HEALTH SURVEYS ■ CLINICAL TRIALS ■ WEIGHT LOSS MONITORING ■ MEDICAL PRACTICE ■ RESEARCH ■ EPIDEMIOLOGY

BIA TECHNOLOGY FOR ASSESSING BODY FAT

AN INTRODUCTORY GUIDE FOR CLINICAL AND RESEARCH APPLICATIONS

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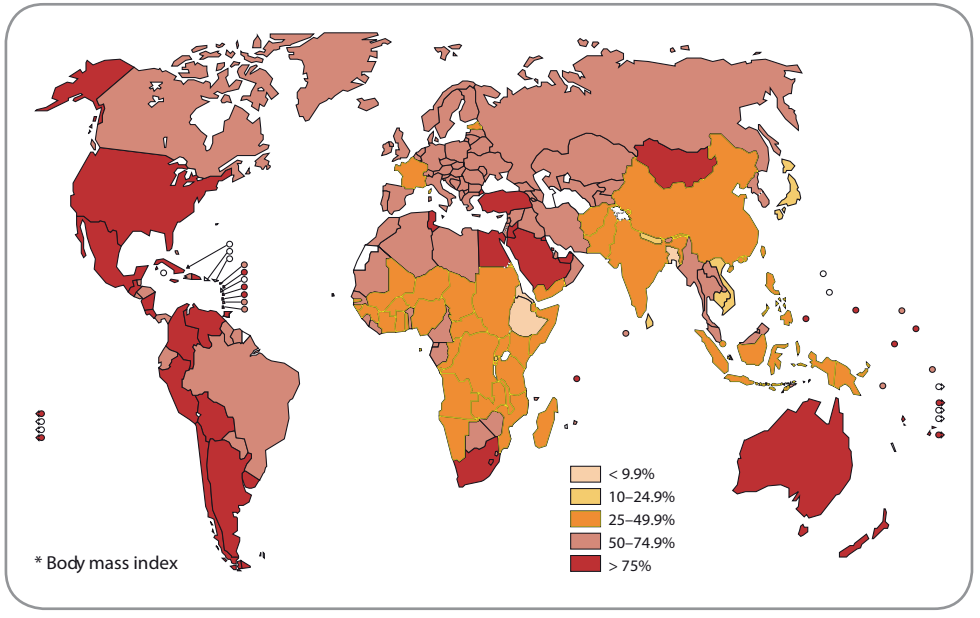
OBESITY AND ENDOCRINE CLINICS ■ GENERAL PRACTICE SURGERIES ■ MOBILE HEALTH SURVEYS ■ FITNESS CENTRES

TANITA
Monitoring Your Health

WHY DOES BODY FAT MATTER?

Obesity is one of the leading modifiable risk factors for chronic diseases in the developed world and is rapidly affecting emerging countries [1-4]. The link between obesity and Type 2 diabetes is especially strong: serious obesity can increase the likelihood of diabetes by almost 100-times, and even slight excesses of body fat are associated with a significant extra risk (5,6).

Figure 1: Projected global prevalence of overweight (BMI ≥ 25 kg/m²) in adult women by 2015



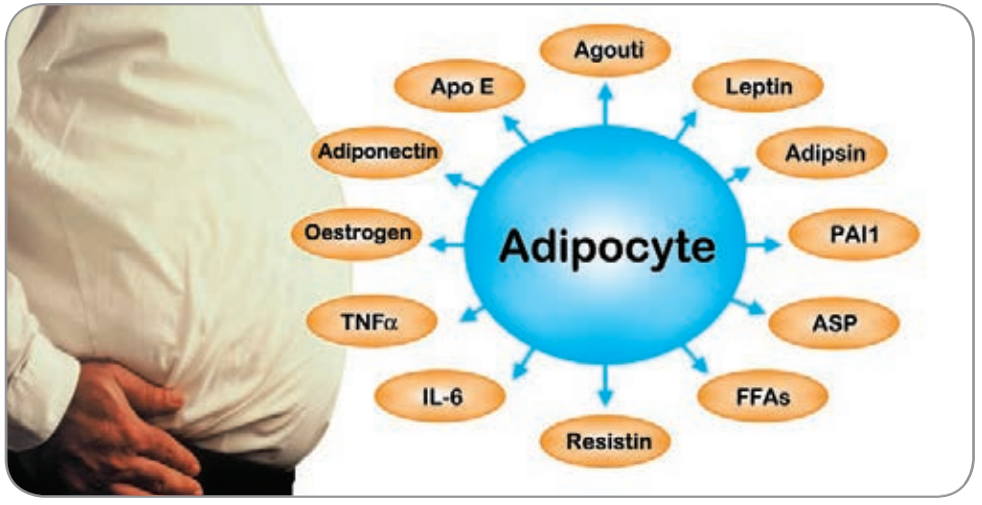
Source: WHO Report 'Preventing Chronic Diseases – A Vital investment' 2005

There are two reasons for the powerful associations between obesity and ill health. First, that obesity is a marker for other risk behaviours such as poor diet and sedentary lifestyles which result in a loss of cardio-respiratory fitness. And second, that the excess fat (adipose tissue) disrupts the body's normal endocrine balance and creates a source of chronic inflammation. It is for these latter reasons that it is important to be able to directly measure the amount of extra fat a person carries and to monitor its changes.

ADIPOSE TISSUE AS A NEW ENDOCRINE ORGAN

Latest research has overturned the long-held view that adipose tissue is merely a passive reservoir of energy. As adipose cells (adipocytes) become over-filled with fat their biochemistry changes. They secrete a wide range of highly bioactive molecules (now called adipokines) with harmful metabolic effects [7-9] (see Figure 2) and they reduce their excretion of the protective adipokine, adiponectin. Excess fat stores also lead to altered sex hormone metabolism with multiple sequelae including ovarian hyper-androgenism.

Figure 2: Metabolic changes in adipose tissue caused by obesity



ADIPOSE TISSUE AS A SOURCE OF INFLAMMATION

The harmful changes illustrated in Figure 2 occur within each adipocyte, but recent research has pointed to another metabolic defect that occurs when adipose tissue becomes overfull. For reasons that are not yet understood, expanding adipose tissue secretes factors that attract inflammatory macrophages [10]. These macrophages invade and colonise the fat stores. They secrete inflammatory cytokines such as IL-6 and TNFα that cause both local and systemic inflammation. These and other inflammatory markers that are strongly correlated with excess

fat (eg sialic acid) are strong predictors of the metabolic syndrome – a constellation of hypertension, hyperlipidaemia and insulin resistance that underlies much chronic cardio-vascular ill health [11,12].

THE INFLUENCE OF FAT DISTRIBUTION

Epidemiological studies relating body fat to ill health have shown that intra-abdominal (or visceral) fat is more harmful than peripheral subcutaneous fat [13]. Obesity characterised by high levels of central abdominal fat is typically seen in men with a paunch and is hence described as android, whilst peripheral obesity is described as gynoid. The terms 'apple-shaped' and 'pear-shaped' have been adopted for lay audiences. Central fat can be assessed moderately well simply by measuring a person's waist circumference (see below).

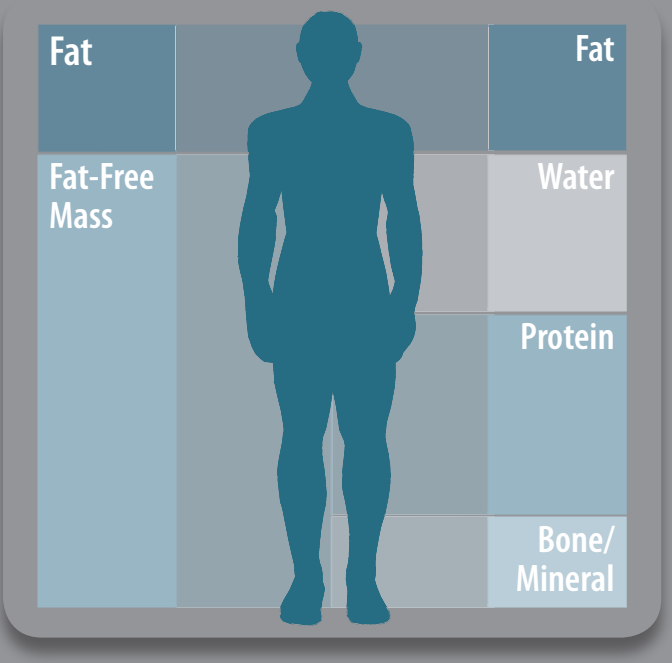
WHAT METHODS ARE AVAILABLE FOR MEASURING BODY FAT?

BIOELECTRICAL IMPEDANCE ANALYSIS (BIA)

BIA assesses body fat by passing a very small current through the body and assessing differences in impedance caused by the fact that fat and lean tissues have different electrical properties. As BIA is the focus of this report it is described in more detail later.

ANTHROPOMETRY (SKINFOLD THICKNESS)

Since much adipose tissue is stored subcutaneously a rough estimate of the amount can be obtained by using callipers to measure skinfold thicknesses at a variety of sites on the body (usually biceps, triceps, supra-iliac and sub-scapular). Nomograms or equations are available that convert these values into estimates of total body fat based on some old experiments that calibrated skinfolds against hydro-densitometry. These are specific to Caucasians and are increasingly unreliable as populations become fatter.



HUMAN BODY COMPOSITION – THE FUNDAMENTALS

Human body composition can be subdivided in many and complex ways, but for most clinical and health-related purposes it is the relative proportion of fat vs lean tissue that matters.

The following basic definitions and abbreviations are useful:

- **Fat mass (FM):** the total amount of fat in a body including that in nerve tissues and the brain.
- **Fat-free mass (FFM):** all the remaining tissues including fluids and the skeleton.
- **Lean-body mass (LBM):** usually used inter-changeably with FFM.

PLETHYSMOGRAPHY

Because adipose tissue is lighter that lean tissue it is possible to calculate the lean-to-fat ratio from a person's density. To calculate density it is necessary to know both weight and volume. Plethysmography measures body volume by placing the subject in an airtight capsule and measuring how much air they have displaced. The method works well but requires subjects to wear bathing costumes and takes time. The apparatus is costly and non-transportable.

HYDRO-DENSITOMETRY

Hydro-densitometry, often called under-water weighing, is an alternative way of measuring body volume – this time by water displacement. Legend tells us that when Archimedes discovered this technique of hydrostatics to test whether King Hiero's crown was made of solid gold he leapt from his bath and ran down the street naked shouting Eureka! Modern subjects must also strip down to a bathing suit and be confident to lie still underwater – hence the measurement is not widely applicable.

DUAL-XRAY ABSORPTIOMETRY (DXA)

DXA body scanners used in clinical practice to measure bone density can also give an estimate of body composition. They use 'soft' X-rays that have a different level of attenuation as they pass through fat and lean tissue. The system can be calibrated using animal carcasses. DXA is considered one of the best methods for assessing body fat and can give regional measures for the limbs and trunk. The equipment is expensive, non-transportable and measurements are time consuming.

BODY WATER ESTIMATION

Body fat contains no water and lean tissue contains, on average, 73% water. Thus by assessing a person's total body water it is possible to compute their lean body mass (LBM) or fat-free mass (FFM), and to calculate fat mass by subtracting FFM from total body weight. Total body water can be measured by giving a dose of deuterium and measuring its dilution in samples of saliva or urine. The main problems are that the deuterium must be measured by sending samples to a mass spectrometry lab which is both costly and time consuming.

NEAR-INFRARED INTERACTANCE

Single-site near-infrared interactance measures body fat on the principle that lean and fat tissues reflect different amounts of infrared radiation emitted by a small probe placed against the skin. This method performs poorly in validation tests – probably because of its inherent assumption that measuring body fat at a single site (usually the triceps) gives an adequate representation of whole-body fat.

OTHER HIGHLY TECHNICAL METHODS

There are a variety of other methods each of which has some significant advantages for assessing body composition, but each of these is highly technical and very expensive. These include: total-body potassium-40 counting (TBK); in vivo neutron activation analysis (NAA); computerized axial tomography (CAT scanning); magnetic resonance imaging (MRI) or spectroscopy (MRS); and total body electrical conductivity (TOBEC). These are used by a very small number of centres worldwide and only for detailed research studies.

IS THERE A GOLD STANDARD FOR MEASURING BODY FAT?

No. The only truly reliable way of assessing body composition is by chemical analysis of cadavers. Such measurements have been applied to humans in the 1940s and the results still form the basis of some of the assumptions used in the methods described above – but cadaver analysis is not a popular method with either researchers or their subjects!

The next best thing is the so-called 'four-compartment model' in which results from three or more of the high-tech methods described above (eg DXA, plethysmography and deuterium dilution) are combined in a mathematical model that helps to minimise errors introduced by the assumptions inherent in each of the methods when applied in isolation. The four-compartment model has been used in the best of the validation studies of BIA described below, but is clearly impractical except in a sophisticated research setting.

WHAT OTHER MONITORING TOOLS ARE AVAILABLE?

There are several methods available that provide a rough proxy of body fatness. Because of their simplicity of measurement they can be used in large-scale surveys and hence have been widely adopted despite their acknowledged limitations.

WEIGHT CHARTS AND TABLES

In years gone by fatness was assessed by expressing a person's weight (adjusted for frame size) against tables of so-called 'ideal body weight' drawn from life insurance company mortality records. This practice is now obsolete for adults, but children's growth progress is still charted on growth curves derived from studying large numbers of healthy, well-nourished children. WHO have recently issued new curves based on breast-fed babies [14].

BODY MASS INDEX (BMI)

The most widely used measure of obesity is the body mass index (BMI) calculated as a person's weight in kilograms divided by their height in metres squared (kg/m^2). The usefulness of BMI is based on the fact that the confounding effects of people being of different height are cancelled out by expressing body weight relative to the square of height.

WHO classifications of body weight based on BMI are as follows: BMI $<18.5 kg/m^2$ = underweight; BMI 18.5-24.9 = normal; BMI 25.0-29.9 = overweight; BMI > 30.0 = obese [15]. It is important to note that these cut-offs are based on arbitrary divisions and are not applicable for Asians (for whom there is a different set of cut-offs [16]).

WAIST CIRCUMFERENCE

Waist circumference needs to be measured carefully with reference to anatomic markers and ideally should be done without clothing. A variety of waist circumference cut-offs have been proposed to help describe people according to health risk categories. The most commonly used are 80cm for women and 94cm for men indicating 'increased risk' and 88cm for women and 102cm for men indicating 'substantially increased risk' [2]. These cut-offs were originally chosen as being the population equivalents of a BMI of 25 and 30 kg/m^2. Other cut-offs have been proposed based on direct studies of the associations between waist size and ill health [17]. Measuring waist circumference requires intimate contact with the patient and is unacceptable to some ethnic and religious groups especially for women. A recent MORI poll showed that 75% of doctors do not use a tape measure on overweight or obese patients mainly due to embarrassment and inconsistent measurements.

WAIST-HIP RATIO

The waist:hip ratio (WHR) used to be a popular measure. It has been superceded for a variety of reasons but primarily because a single figure for waist circumference is simpler. Many would argue that WHR remains a better method because the hip measurement gives an indication of whether muscle mass has been lost, and this is an important predictor of poor glucose tolerance.

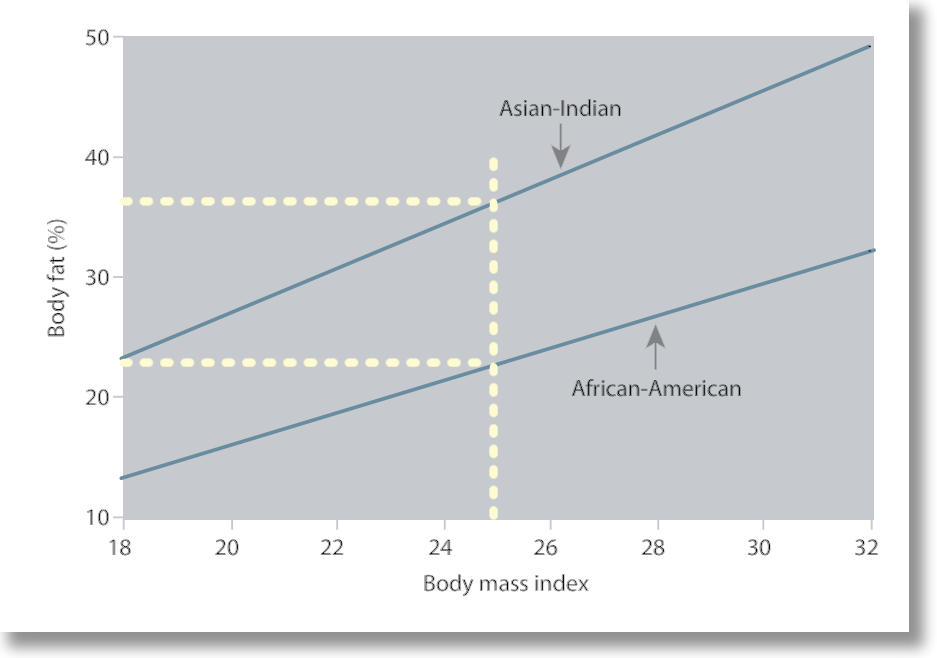
WHY IS IT IMPORTANT TO ACTUALLY MEASURE BODY FAT?

Simple proxy measures of body fat such as BMI and waist circumference have been enormously useful in epidemiological studies and population surveys. They have served to demonstrate the strong associations between obesity and chronic ill health, and have adequately described the global pandemic of obesity. However they are far from perfect and may frequently be misleading. Some examples of potential pitfalls are illustrated below.

RACIAL DIFFERENCES IN THE BMI TO BODY FAT RELATIONSHIP

One of the key problems with BMI, especially when using it to estimate international trends or to form the basis of treatment thresholds, is that there is a profoundly different relationship between BMI and actual body fat across different racial groups [18-20]. Figure 3 shows the extreme examples of Asians against African-Americans. The dotted lines show that at a BMI of 25 kg/m^2 an African-American will typically have 23% body fat whilst an Asian will typically have 36% fat: an 'error' of over 50%.

Figure 3: Racial differences in the relationship between BMI and body fat



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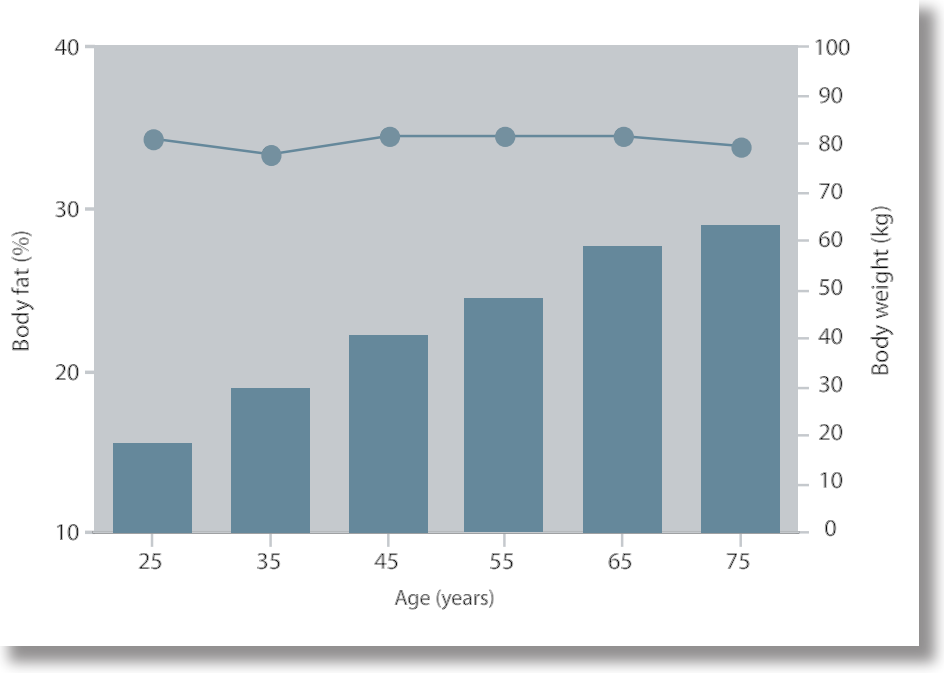
BMI FAILS TO REVEAL AGE-RELATED CHANGES IN THE LEAN:FAT RATIO

A gradual replacement of lean by fat tissue is a normal feature of ageing, at least in Western societies. The data from American men in Figure 4 shows this to be a very significant effect with average body fat rising from about 15% in 20-year-olds to almost 30% in 75-year-olds [21,22]. Note that in this sample BMI remained constant and hence completely misses this important transformation in body composition.

Figure 4: Age-related increase in body fat (solid bars) for normal men at constant BMI



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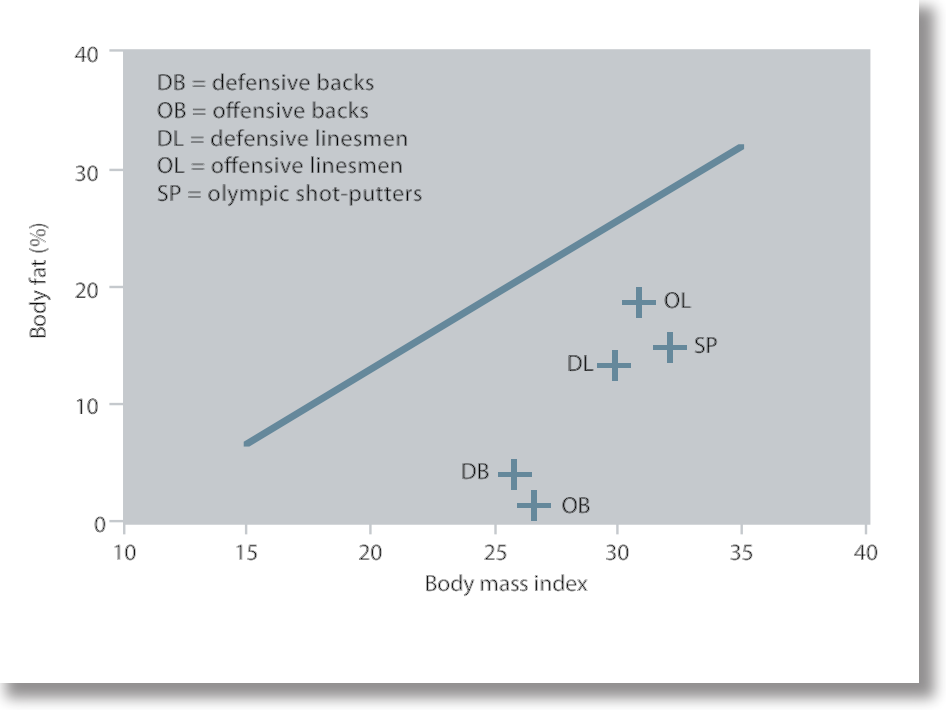
BMI MISCLASSIFIES OBESITY IN ATHLETES

Another example of misclassification by BMI relates to athletes and those engaged in any form of manual labour or training that tends to maintain a high muscle mass. The typical relationship between BMI and body fat in men shown by the line in Figure 5 can overestimate actual body fat in athletes by a factor of 2 or more.

Figure 5: Mismatch between BMI and body fat in sportsmen



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BMI FAILS TO TRACK EXERCISE-INDUCED CHANGES IN BODY COMPOSITION

Exercise plays a critical role in maintaining optimal body weight, body composition and health, but monitoring its advantages can sometimes be problematic. For instance, many people who start exercising find that they do not lose weight and hence become demotivated. This is frequently because they are replacing fat with lean tissue. The advantages of this transformation are enormous, but may not be detected unless the person has their body composition monitored as their training progresses – hence the popularity of body composition analysers in good quality gyms.

Exercise is also recommended in most good weight loss regimes, but again the true benefits will not be seen unless body composition is monitored. Figure 6 shows data from an intensive weight loss scheme [23]. Patients following the moderate and high exercise arms of the study lost more weight than the no exercise control arm, but the advantages become even more clear in terms of the composition of the tissue lost: lean tissue represented almost 30% of the weight lost by the control group and only 18-20% in the exercise groups. There are numerous similar examples in the literature [eg 24].

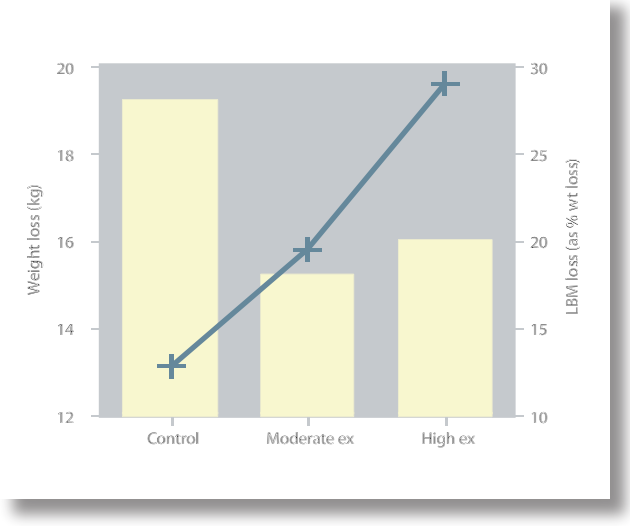

Figure 6: Effect of exercise on weight loss (line) and composition of weight loss (bars) during dieting

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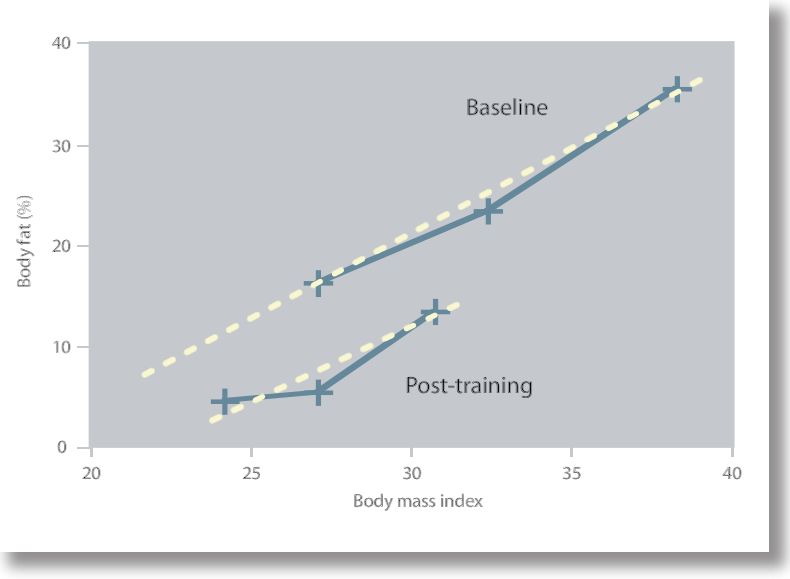
These changes can be even more profound if the training regime is intensive. Figure 7 shows data in three groups of soldiers whose BMI and body fat were measured at baseline and again after an extreme army-training scheme [25]. Rather than just moving down towards the left-hand end of the upper dotted line the fundamental relationship between BMI and body fat was profoundly altered. If judged on BMI alone the middle group would have indicated a change in body fat from 23% to 17%. In fact the true change was from 23% to 5% indicating a 3-fold error if monitored by BMI.

Figure 7: Training profoundly alters the BMI to body fat relationship in soldiers



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THE U-SHAPED RELATIONSHIP BETWEEN BMI AND MORTALITY MAY BE MISLEADING

Many population-based studies of mortality have revealed an inverse J-shaped relationship between BMI and mortality. As BMI increases there is a marked additional risk of premature death, but there is also a slight excess at the far lower end of the BMI range.

Research on large population cohorts in Denmark shows that this relationship may be concealing two independent effects – namely that risk is elevated both by an increased body fat and by a reduced fat-free mass [26].

This is shown in Figure 8. These two opposing effects cancel each other out when estimates are based simply on BMI, and hence have obscured a proper understanding of the issue. Similar analyses of mortality data from the large (US National Health and Nutrition Examination Surveys (NHANES) also emphasise the importance of deconstructing the separate health effects of fat mass and fat-free mass, and hence the importance of assessing body composition [27,28]. A failure to do so in previous surveys has delayed some important public health messages in terms of the importance of building up and maintaining lean tissue. If such large-scale surveys could have been based on measures of body composition these potentially critical insights would have emerged much sooner.

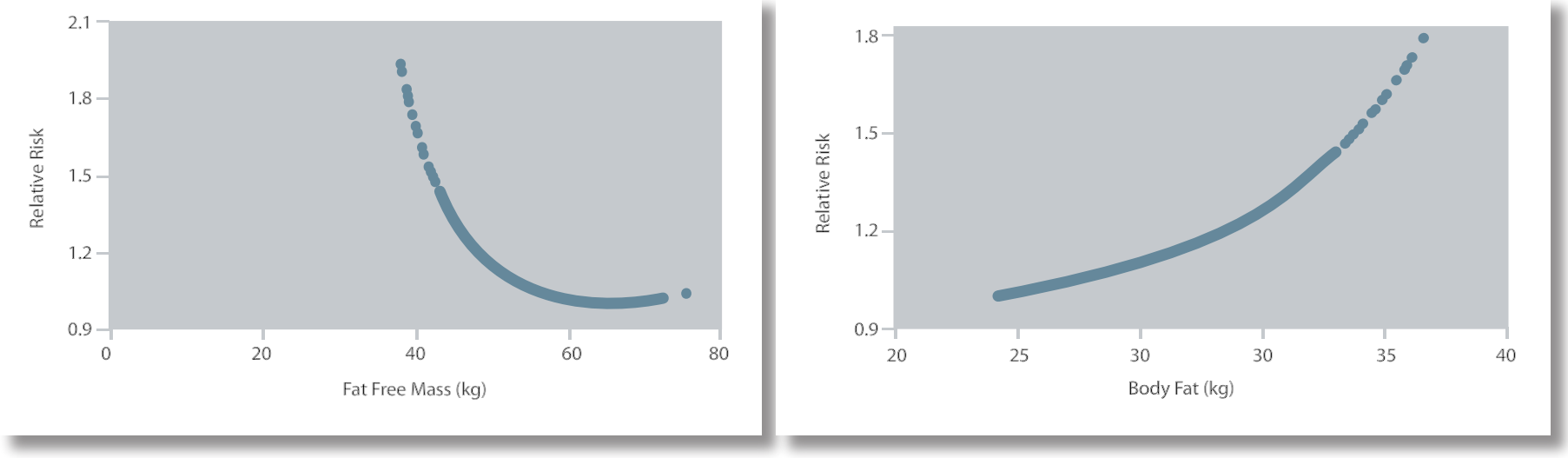
BMI FAILS TO DETECT IMPORTANT GENDER DIFFERENCES IN BODY COMPOSITION DURING GROWTH AND DEVELOPMENT

As discussed in more detail below (see Figures 9 and 10) the BMI growth curves developed for children and adolescents fail to detect very important differences in body composition that develop between boys and girls as they progress through puberty. BIA detects these differences and allows a proper understanding of the underlying physiological processes.

WAIST CIRCUMFERENCE SOMETIMES DOES NOT PREDICT ILL-HEALTH

A study of almost 7,000 deaths from a cohort of 15,000 elderly people (>75 years) in the UK revealed that waist circumference did not predict mortality, but there were very strong relationships with the waist-hip ratio (WHR) [29]. Although this study did not have measures of body composition the implications of the findings are that maintenance of a good muscle mass (indicated by the hip component of the WHR) is critical to health and survival in the elderly. Other studies support this inference and point to the advantage of being able to disaggregate changes in fat and fat-free mass when determining optimal body size and composition. Although the data described are from the elderly, the principle is important at all ages.

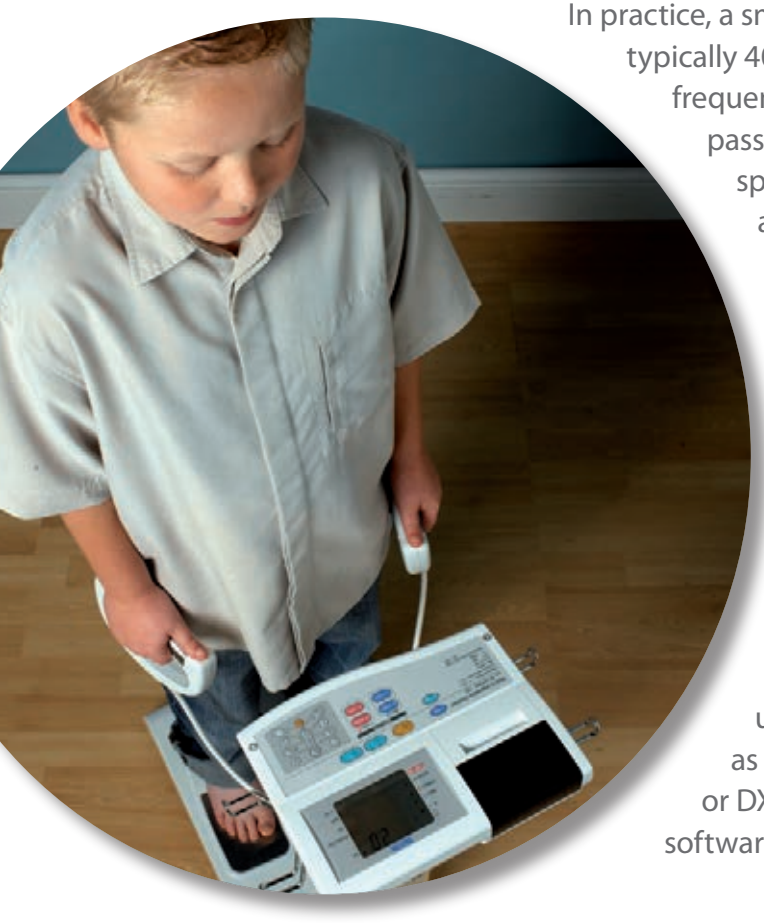
Figure 8: Increased risk of mortality is predicted both by increased fat mass and by diminished fat free mass



Data from 60 year-old Swedish men. Reproduced with permission from Heitmann 2000.

HOW DOES BIA WORK?

Bio-electrical Impedance Analysis (BIA) measures the impedance or resistance to the flow of a safe, low-level electric current through the body fluids contained mainly in the lean tissue. Impedance is low in lean tissue, where intra-cellular and extra-cellular fluid and electrolytes are primarily contained, but high in fat tissue. Impedance is thus proportional to total body water (TBW). Lean body mass is then calculated from this estimate using an assumed hydration fraction for lean tissue of 73.2%; the same assumption used in several other body composition methods. Fat mass is calculated as the difference between body weight and lean body mass.



In practice, a small constant current, typically 400 µA at a fixed frequency, usually 50 kHz, is passed between electrodes spanning the body and the voltage drop between electrodes provides a measure of impedance. Prediction equations, previously generated by correlating impedance against total body water (TBW) measured using a method such as deuterium dilution or DXA, are built into the software of BIA monitors.

The impedance of a biological tissue comprises two components, the resistance and the reactance. The conductive characteristics of body fluids provide the resistive component, whereas the cell membranes, acting as imperfect capacitors, contribute a frequency-dependent reactive component. By measuring the impedance at different frequencies (eg 5 kHz and 200 kHz) and by applying predictive equations, it is possible to estimate both Extra-Cellular Water (ECW) and TBW respectively and by deduction, Intra-Cellular Water (ICW). ECW can be related to extra-cellular mass (ECM) and ICW to Body Cell Mass (BCM).

WHAT IS NOVEL ABOUT TANITA BIA MONITORS?

Tanita pioneered the use of foot-to-foot BIA in which subjects simply have to remove their shoes and stand on a monitor that sends a minute current from one foot to the other. The measurement can be completed in 20 seconds, and is backed by a strong research programme over 15 years. There was initial scepticism as to whether a system just passing a current though the legs could be as accurate as previous 'tetrapolar' systems that attached stick-on electrodes to each ankle and each wrist. However, later research showed that (because they represent a very long thin conductor) arms actually introduce a disproportionate weighting to tetrapolar monitors and may hence reduce their accuracy if not adjusted for carefully.

The new generation of advanced professional models of Tanita BIA use 8-electrodes and require subjects to hold two hand-grips whilst standing on the monitor. This now allows segmental analysis of the composition of arms, legs and trunk. The trunk value is particularly important in terms of assessing abdominal fat.

WHAT ARE THE ADVANTAGES OF BIA?

- Differentiates fat and lean tissue
- Monitors composition of weight loss
- Some versions provide segmental analysis (trunk, legs, arms)
- Simple and fast to perform
- Highly suitable for large-scale health surveys
- Print-out of results
- Data capture options available
- Portable equipment (mains or battery operation)
- Non-invasive (does not require undressing)
- Low risk (meets all EU quality directives MDD, CE and NAWI)
- Low cost compared to other high-tech methods
- High predictive value (extensive validations)
- Excellent consistency for repeated measurements
- Sensitive enough to detect clinically important differences
- Body fat centile curves based on Tanita technology available for children and adolescents

WHAT ARE THE LIMITATIONS OF BIA?

- Not recommended for use by patients with pace-makers
- Not as accurate as the 'gold standard' 4-compartment model
- Versions not yet available for children under 5 years
- Patients must be able to stand on the monitor for leg-to-leg versions

COMPARISONS OF BODY COMPOSITION METHODS

METHOD	COST	ACCURACY	EASE OF USE	SPEED OF USE	PORTABILITY	PATIENT ACCEPTABILITY
TANITA BIA	+ to ++	+++ [2]	+++	+++	+++	+++
OTHER BIA	+ to ++	+++ [2]	++	++	+++	++
INFRA-RED INTERACTANCE	+	+	+++	+++	+++	+++
PLETHYSMOGRAPHY	+++	+++	++	+	-	+
HYDRODENSITOMETRY	+++[1]	++++	-	-	-	-
DXA	+++	++++	-	+	-	+
BODY WATER DILUTION	+++	++++	-	-	-	+
TOBEC	++++ [1]	?	-	-	-	-
MRI or MRS	++++	++++	-	-	-	-
CAT	++++	+++	-	-	-	-
TBK	++++ [1]	+++	-	-	-	-
NEUTRON ACTIVATION	++++ [1]	++++	-	-	-	-
4-COMPARTMENT MODEL	++++ [1]	++++	-	-	-	-
SKINFOLDS	+	++	++	++	+++	++
BMI	+	++	+++	+++	+++	+++
WAIST CIRCUMFERENCE	-	++	++	+++	+++	++

[1] Not commercially available. [2] Based on Jebb et al [31]

VALIDATION STUDIES

The original prediction equations built into Tanita's BIA software were derived by Prof Steven Heymsfield's research team at St Luke's/Roosevelt Hospital, College of Physicians and Surgeons, Columbia University, New York.

Tanita BIA monitors have been more extensively validated against alternative body composition techniques than other variants of BIA. The results are in the published literature [eg 31-33]. A selection of other studies published in abstract form can be found at: *http://www.tanita.co.uk/professional_index.cfm?page=professional_resource04.*

Validation studies need to be interpreted with two things in mind. First, that some of them refer to generations of BIA monitors that have been superseded by newer models. Second that, unless validated against the 4-compartment model (the closest we have to a 'gold standard') then it should be remembered that any apparent error and bias will have a component contributed by the inaccuracy and imprecision of the comparator method.

CROSS-SECTIONAL VALIDATION (ABILITY TO COMPARE BODY COMPOSITION ACROSS INDIVIDUALS)

Pietrobelli and colleagues have validated the latest generation of 8-electrode segmental analyzer (BC-305) and the older 4-electrode analyzer (TBF-310) against DXA measurements in 20 men and 20 women aged 6 to 64 years [30]. They assessed the ability to measure %body fat, lean soft tissue (LST) and appendicular lean soft tissue (ALST = LST in arms, legs and total). The within- and between-day coefficient of variation for %fat and ALST evaluated in five subjects was <1% and ~1–3.7%, respectively.

The correlations between 8-electrode predicted and DXA appendicular and trunk & head LST were strong and highly significant (all r>0.95, P<0.001) and group means did not differ across methods. Skeletal muscle mass calculated from total ALST by DXA (23.7 ± 9.7 kg) was not significantly different and highly correlated with BC-418 estimates (25.2 ± 9.6 kg; r = 0.96, P<0.001). There was a good correlation between total body %fat by 8-electrode BIA vs DXA (r = 0.87, P<0.001). Segmental %fat estimates from BC-418 did not differ significantly from corresponding DXA estimates. No between-method bias was detected in the whole body, ALST, and skeletal muscle analyses. The authors concluded that: 'The new 8-electrode BIA system offers an important new opportunity of evaluating skeletal muscle in research and clinical settings. The additional electrodes of the new BIA system also improve the association with DXA %fat estimates over those provided by the conventional foot–foot BIA.'

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www.nature.com/ejcn

ORIGINAL COMMUNICATION

New bioimpedance analysis system: improved phenotyping with whole-body analysis

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Objective: Bioimpedance analysis (BIA) is a potential field and clinical method for evaluating skeletal muscle mass (SM) and %fat. A new BIA system has 8 (two on each hand and foot) rather than 4 contact electrodes allowing for rapid 'whole body' and

LONGITUDINAL VALIDATION (ABILITY TO MEASURE CHANGES IN BODY COMPOSITION)

Jebb and colleagues used a weight loss study in which 58 women lost an average of 9.9 ± 3.5kg but after 1 year had regained 4.9 ± 3.7kg to test the validity of leg-to-leg bioimpedance (LTL: Tanita BC418) against a 4-compartment (4-C) model based on air displacement plethysmography (ADP), deuterium dilution - total body water (TBW) and dual-energy X-ray absorptiometry (DXA) [32]. Skinfold thickness (SFT) and tetrapolar bioelectrical impedance analysis (T-BIA) were also compared.

The estimate of body fat change by LTL relative to the 4-compartment model (bias during weight loss = 0.51 ± 1.63kg; bias during weight regain = -0.25 ± 2.30kg) was similar to the more complex ADP, DXA and TBW methods in both phases, and was better than tetrapolar-BIA and skinfold thickness. The authors concluded that: 'The LTL system is a useful method to measure body composition changes during clinical weight management.'

International Journal of Obesity (2006) 1–7

0307-0565/06 $30.00
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ORIGINAL ARTICLE

Validity of the leg-to-leg bioimpedance to estimate changes in body fat during weight loss and regain in overweight women: a comparison with multi-compartment models

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Objectives: To investigate changes in body composition and the validity of the leg-to-leg bioimpedance (LTL) method to measure body fat during active weight loss (WL) and weight regain (WR).
Design: Longitudinal, 12-week weight loss intervention (3.3–3.8 MJ/day) and subsequent follow-up at 1 year.
Subjects: Fifty-eight adult women aged between 24 and 65 years (mean age: 46.8±8.9 years) and with a body mass index (BMI) ⩾25 kg/m^2 (mean BMI: 31.6±2.5 kg/m^2, range=26.0–48.2 kg/m^2) participated in the study.
Measurements: Fat mass (FM) was measured at baseline, 12 weeks, 24 weeks and 52 weeks using three- and four-compartment (4-C) models, air displacement plethysmography (ADP), deuterium dilution – total body water (TBW), dual-energy X-ray absorptiometry (DXA), skinfold thickness (SFT), tetrapolar bioelectrical impedance analysis (T-BIA) and LTL.
Results: At the end of the weight loss programme, subjects lost 9.9±3.5 kg weight ($P<0.001$) and 7.6±0.5 kg fat ($P<0.001$) but after 1 year they had regained 4.9±3.7 kg of weight and 3.7±2.9 kg of fat. The 4-C model showed that FM and TBW

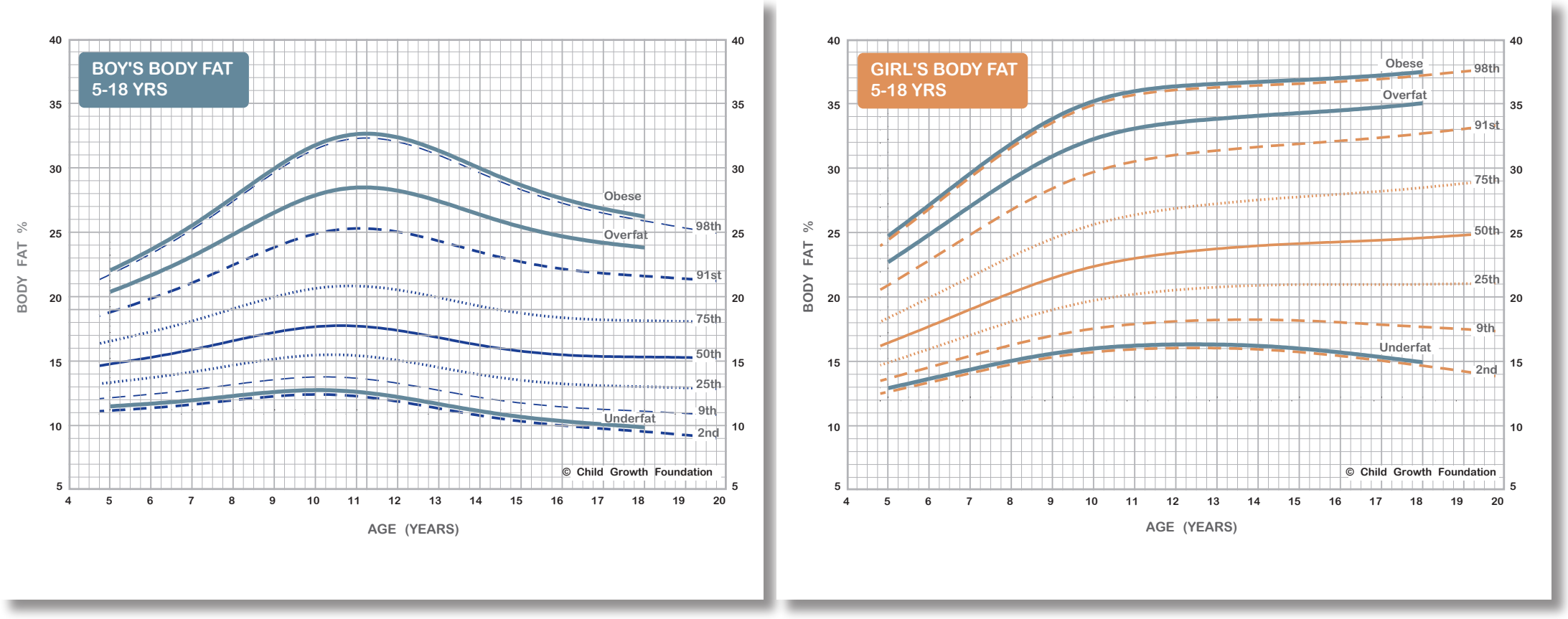
CASE STUDIES

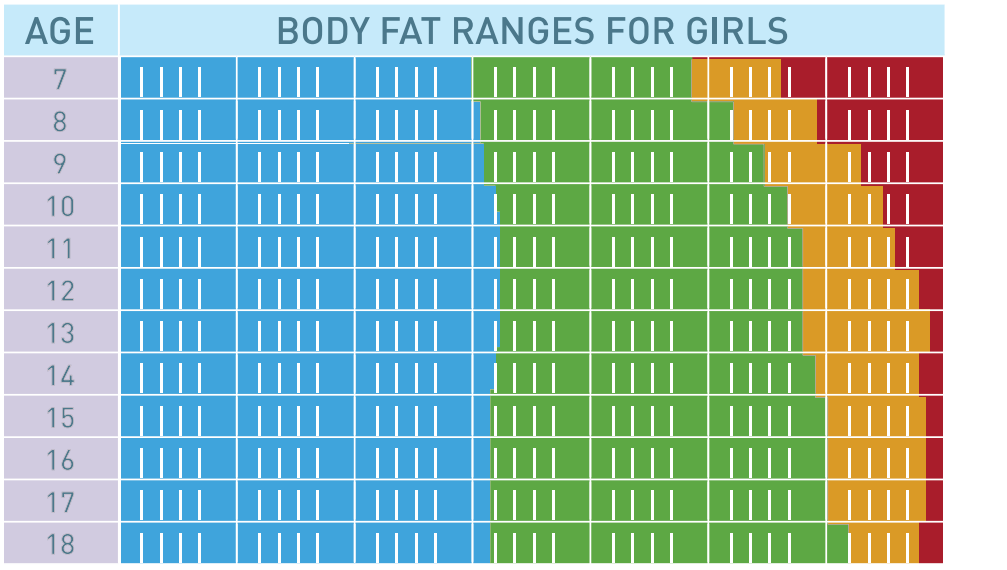
DEVELOPMENT AND APPLICATION OF BODY FAT CENTILE CURVES FOR CHILDREN

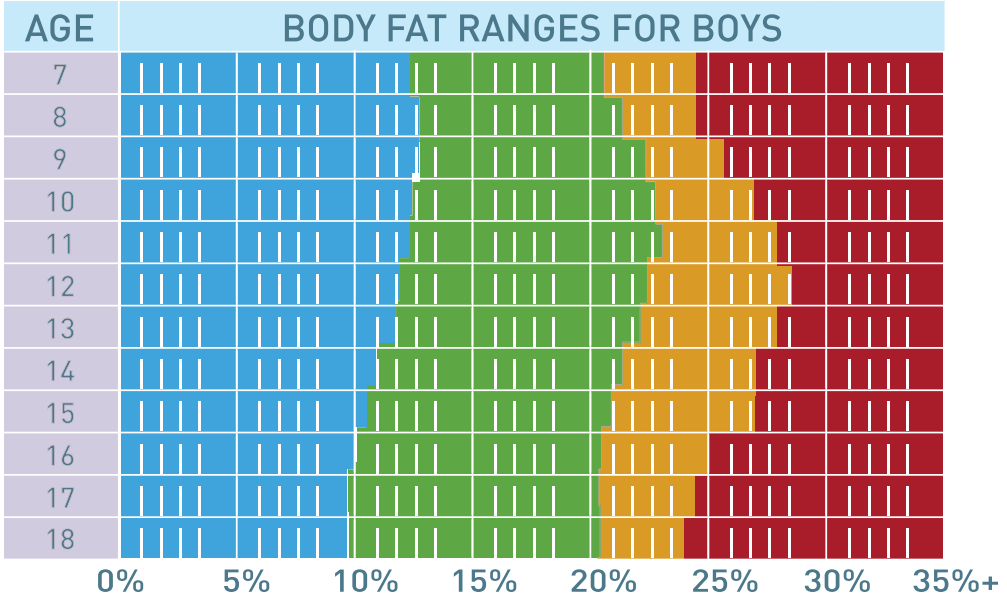
Growth centile charts for children have been used in paediatric practice for several decades. In the 1990s these were augmented by BMI centile charts first available in the UK and then in international versions. The intention of BMI charts is to aid in the diagnosis of overweight and obesity in children, but as summarised above BMI can misclassify some children, especially those with a large frame and solid build. Hence centile charts based on actually measures of body fat would be advantageous.

The first generation of such charts has now been developed based on a study of almost 2000 British school children aged 5 – 18 years whose body composition was assessed using the Tanita BC-418 [33]. The shapes of the body fat curves shown in Figure 9 clearly show the gender differences in body fat that occur during puberty: boys increase their fat mass until puberty but then replace fat by muscle mass; girls continue to increase their fat stores as puberty progresses. Note that these important sex differences are completely concealed by BMI charts which look very similar in boys and girls because BMI cannot distinguish fat from lean tissue. The new body fat charts are available from the Child Growth Foundation *(www.cgf.co.uk)*. Tanita monitors come with a simplified version of these charts illustrated in Figure 10.

Figure 9: Paediatric body fat centile charts for use in growth monitoring







UNDERFAT | HEALTHY | OVERFAT | OBESE

Jebb S, McCarthy D, Fry T, Prentice AM New body fat reference curves for children. Obesity Reviews (NAASO Suppl) 2004, A146.

Figure 10: Tanita's body fat centile ranges for children

RESEARCH APPLICATIONS IN THE AFRICAN BUSH

Research studies funded by the UK Medical Research Council and the European Union as part of the EARNEST Programme investigating how early nutritional interventions can affect later health have recently completed measurements in over 1500 children in rural Gambia. Tanita BC-418 body composition analysers formed part of the field laboratory transported by LandRover around 25 remote villages. Powered off a car battery or a small portable generator the BC-418s proved highly durable and simple to use.

COMMUNITY-BASED CHILDREN'S WEIGHT LOSS PROJECT

A community-based weight loss project funded by London's Tower Hamlets Borough and Primary Care Trust has used the Tanita BC418 monitor to assess the effects of a 12-week weight management programme in 5-13 year old children. As would be expected the children grew in stature but most showed a decrease in fat mass; a fact that was undetected by following their changes in BMI [34].

A SURVEY OF POSSIBLE MISCLASSIFICATION OF OVERWEIGHT AND OBESITY IN SCHOOL CHILDREN

In a study of 1671 caucasian Chichester school children aged 11-14 years Potter and colleagues used the Tanita BC418 segmental analyser to compare how the prevalence of overweight and obesity differed according to whether classification was made using BMI charts or the new body fat charts referred to above [35]. They found that as many as 23% of the sample were classified differently by the two methods. This could have significant implications both for survey methodology and treatment.

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PEDIATRIC HIGHLIGHT

Body fat reference curves for children

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Objective: To refine the diagnosis of childhood obesity by creating new sex-specific centile curves for body fat and to base these references on a simple and affordable method that could be widely adopted in clinical practice and surveys.
Design: Body fat was measured by bio-impedance in 1985 Caucasian children aged 5–18 years from schools in Southern England. Smoothed centile charts were derived using the LMS method.
Results: The new body fat curves reflect the known differences in the development of adiposity between boys and girls. The curves are similar by sex until puberty but then diverge markedly, with males proportionately decreasing body fat and females continuing to gain. These sex differences are not revealed by existing curves based on body mass index. We present charts in which cutoffs to define regions of 'underfat', 'normal', 'overfat' and 'obese' are set at the 2nd, 85th and 95th centiles. These have been designed to yield similar proportions of overweight/overfat and obese children to the IOTF body mass index cutoffs.
Conclusions: Direct assessment of adiposity, the component of overweight that leads to pathology, represents a significant advance over body mass index. Our new charts will be published by the Child Growth Foundation for clinical monitoring of body fat, along with the software to convert individual measurements to *Z*-scores.
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Keywords: children; centiles; body fatness; bioelectrical impedance; Caucasian

SUMMARY

The rapidly escalating prevalence of obesity throughout the world brings with it new threats to the health of nations that require a concerted effort by scientists and public health workers alike. Monitoring of body composition, and especially of excess body fat, represents a key element that should underpin interventions at both the individual and the community level. This document has summarised the principles of BIA, and provides a comparison of its advantages and limitations against other possible methods.

Although other techniques are slightly more accurate than BIA they all suffer the limitations ranging from much greater purchase and running costs, technical complexity, non-portability, risk (eg from Xrays) and time taken for measurements. These prevent them from being used in busy clinics, health centres or sports facilities, and in large-scale surveys.

In such settings and for many applications BIA represents the best currently-available option for assessing body composition, and its wider adoption will almost certainly enhance our understanding of how the obesity pandemic is influencing human health and hence our ability to work towards a leaner, fitter future.

This report was commissioned from Prof Andrew M. Prentice, PhD.

Professor Prentice is head of the MRC International Nutrition Group at the London School of Hygiene & Tropical Medicine and Director of the Nutrition Programme at MRC Laboratories, The Gambia. He is a member of the Tanita Medical Advisory Board. The views presented are his own and do not imply endorsement by MRC of LSHTM.

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HEALTH RISKS OF EXCESS FAT IN CHILDREN

obesity = excess fat → disease

Children

Lungs
3-fold increased chance of asthma in obese girls
Wickens K *et al* (2005) Obesity and asthma in 11-12 year old New Zealand children in 1989 and 2000.
Thorax; 60: 7-12.

Head
12 point reduction in quality-of-life (QoL) scores
5-fold more likely to report impaired health-related QoL
Schwimmer JB *et al* (2003) Health-related quality of life of severely obese children and adolescents.
J Am Med Assoc; 289: 1813-9.

Throat
20% increased risk of sleep-related breathing disorders
Wing YK et al (2003) A controlled study of sleep related disordered breathing in obese children.
Arch Dis Child; 88: 1043-7.

Heart
3-fold increased risk of hypertension
Sorof J & Daniels S (2002) Obesity hypertension in children: a problem of epidemic proportions.
Hypertension; 40: 441-7.

General body
30% moderately obese and 50% severely obese children suffer from the metabolic syndrome
Weiss RN *et al* (2004) Obesity and the metabolic syndrome in children and adolescents.
New Engl J Med; 350: 2362-74.

Liver
77% of obese children have fatty liver disease
24% of these progress to non-alcoholic steatohepatitis
Chan DF *et al* (2004) Hepatic steatosis in obese Chinese children.
Int J Obes; 28: 1257-63.

Pancreas
Type-2 diabetes rapidly becoming more common than type-1
Pontiroli AE (2004) Type 2 diabetes mellitus is becoming the most common type of diabetes in school children.
Acta Diabetol; 41: 85-90.

Reproductive organs
Increased risk of polycystic ovary syndrome (PCOS) in girls
Silfen ME *et al* (2003) Early endocrine, metabolic, and sonographic characteristics of polycystic ovary syndrome (PCOS): comparison between non-obese and obese adolescents.
J Clin Endocrinol Metab; 88: 4682-8.

Bones (arm)
70% increased risk of fracture
Davidson P et al (2003) Biomechanical analysis of arm fracture in obese boys.
J Paediatr Child Health; 39: 657-664.

Kidney
Increased risk of impaired renal function
Csernus K *et al* (2005) Effect of childhood obesity and obesity-related cardiovascular risk factors on glomerular and tubular protein excretion.
Eur J Pediatr; 164: 44-9.

Legs
Reduced exercise tolerance
Marinov B *et al* (2002) Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise.
Clin Physiol Funct Imaging; 22: 254-60.

Children to Adults

Childhood obesity predicts adult health risks
Raitakari OT *et al* (2003) Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: the Cardiovascular Risk in Young Finns Study.
J Am Med Assoc; 290: 2277-83.

Obese children more likely to become obese adults
Freedman DS *et al* (2005) The relation of childhood BMI to adult adiposity: the Bogalusa Heart Study.
Pediatrics; 115: 22-7.

Adults

Lungs
85% increased risk of asthma
Nystad W *et al* (2004) Body mass index in relation to adult asthma among 135,000 Norwegian men and women.
Am J Epidemiol; 160: 969-76.

Head
4.6-fold risk of major depression
Onyike CU et al (2003) Is obesity associated with major depression? Results from the Third National Health and Nutrition Examination Survey.
Am J Epidemiol; 158: 1139-47.

Throat
Most morbidly obese develop obstructive sleep apnea
Aloia MS *et al* (2005) Examining the construct of depression in obstructive sleep apnea syndrome.
Sleep Med; 6: 115-21.

Heart
6-fold increased risk of hypertension
Mokdad AH *et al* (2003) Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001.
J Am Med Assoc; 289: 76-9.

Breasts
2-fold increase in breast cancer
Calle EE *et al* (2003) Overweight, obesity, and mortality from cancer in a prospectively studied cohort of US adults.
New Eng J Med; 348: 1625-38.

Liver
76% of obese adults have non-alcoholic fatty liver disease
Increased risk of cirrhosis and 4.4-fold increased risk of liver cancer
Festi D *et al* (2004) Hepatic steatosis in obese patients: clinical aspects and prognostic significance.
Obes Rev; 5: 27-42.

Pancreas
7-fold increased risk of diabetes in severely obese
Mokdad AH *et al* (2003) Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001.
J Am Med Assoc; 289: 76-9.

Kidney
1.5 to 2.0-fold increased risk of kidney stones
Taylor EN *et al* (2005) Obesity, weight gain, and the risk of kidney stones.
J Am Med Assoc; 293: 455-62.

Uterus
Weight loss in infertile obese women caused 90% resumption of ovulation and 78% pregnancy rate
Clark AM *et al* (1998) Weight loss in obese infertile women results in improvement in reproductive outcome for all forms of fertility treatment.
Hum Reprod; 13: 1502-5.

Bowels
93% increased risk of colon cancer + 65% increased risk of rectal cancer
Pan SY *et al* (2004) Association of obesity and cancer risk in Canada.
J Epidemiol; 159: 259-68.

Ovaries
50% of women with polycystic ovary syndrome (PCOS) are overweight or obese
Gambineri A *et al* (2002) Obesity and the polycystic ovary syndrome.
Int J Obes; 26: 883-96.

Testes
Reduced sperm count
Jensen TK *et al* (2004) Body mass index in relation to semen quality and reproductive hormones among 1,558 Danish men.
Fertil Steril; 82: 863-70.

Legs
4.4-fold increase in arthritis
Mokdad AH *et al* (2003) Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001.
J Am Med Assoc; 289: 76-9.

General body
Increased risk of all cancers except lung, brain, bladder and stomach
Calle EE *et al* (2003) Overweight, obesity, and mortality from cancer in a prospectively studied cohort of US adults.
New Eng J Med; 348: 1625-38.

TANITA
Monitoring Your Health

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