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Original Article

The relationship between BMI and percent body fat, measured by bioelectrical impedance, in a large adult sample is curvilinear and influenced by age and sex

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SUMMARY

Objective: The study aimed to establish the effects of age, gender and age–gender interactions on BMI–% fat relationships over a wide range of BMI and age. It also aimed to examine controversies regarding linear or curvilinear BMI–% fat relationships.
Methods: Body composition was measured using validated bio-impedance equipment (Bodystat) in a large self-selected sample of 23,627 UK adults aged 18–99 (99% ≤70) years, of which 11,582 were males with a mean BMI of 26.3 ± 4.7 (sd) kg/m^2, and 12,044 females, with a mean BMI of 25.7 ± 5.1 kg/m^2. Multiple regression analysis was used.
Results: BMI progressively increased with age in women and plateaued between 40 and 70 years in men. At a fixed BMI, body fat mass increased with age (1.9 kg/decade), as did % fat (1.1–1.4% per decade). The relationship between BMI and % fat was found to be curvilinear (quadratic) rather than linear, with a weaker association at lower BMI. There was also a small but significant age–gender interaction.
Conclusion: The association between BMI and % body fat is not strong, particularly in the desirable BMI range, is curvilinear rather than linear, and is affected by age.

1. Introduction

Many studies have examined the variation in body composition associated with age and gender.[1–12] These have generally used only modest numbers of subjects, as the measurements (with the exception of body mass index (BMI) and bioelectrical impedance) are often time-consuming. The usual pattern in most populations studied is that body fat and percent fat are greater in women than men, and increase until the age of 60 years or more.

The most commonly used indicator of % body fat is BMI (e.g. see validation studies against reference techniques[9,10,13–15]), although it is well known that it has an imperfect association. Muscle mass can vary considerably between individuals of the same height, and it contributes substantially to the variability in BMI, especially in leaner individuals. Many studies have drawn attention to the BMI–% body fat association, often in particular groups of subjects. Recent examples include athletes,[16] military personnel,[17] young adults,[18] and the severely obese.[19] There are also large population studies that provide reference values of body composition based on bioelectrical impedance analysis e.g.[20,21] However, in the general population there is uncertainty and some controversy as to whether the relationship between BMI and % body fat is linear,[10] or curvilinear.[9] There is further uncertainty about the magnitude of the increase in % fat with age after controlling for BMI,[9,11] and even more uncertainty as to whether the age-dependent change in % fat relationship at a given BMI is affected by gender. We wish to add to this body of evidence by analysing a collection of data where body composition is measured directly in a large sample.

We have accumulated a large set of data on body composition in UK adults using bio-impedance measurement equipment (Bodystat Ltd, Douglas, Isle of Man, UK). Validation studies in which % body fat is the outcome variable, have been undertaken in lean and obese Caucasian subjects without disease using Bodystat bielectical impedance equipment and a range of reference techniques, such as the 4 compartment model,[22] 3 compartment model,[22–24] total body water,[22,23] hydrodensitormetry,[22,23] dual energy X-ray absorptiometry (DXA),[22,25,26] and air displacement plethysmography.[27] Bodystat instruments have also been shown to have good test–retest reliability with respect to fat and fat-free mass and in the raw measurements used to estimate body composition.[25,28] We now use this new large data set to examine the significance of gender, age–gender, and age–BMI interactions in predicting

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percent body fat. In doing so we also look at the extent to which changes with age are due to alterations in lean body mass and fat mass.

Our study has the strength of using a large sample of men and women over a wide range of BMI and age across the UK. A drawback is that subjects are largely self-selected, and so we are unable to reliably derive estimates of UK population averages. However, it is still reasonable to expect that the patterns of body composition variation with age and gender are representative of the UK population.

2. Methods

2.1. Subjects

Subject data were obtained from Bodystat® 1500 bio-impedance analyzers (Bodystat Ltd, Douglas, Isle of Man, UK) returned to the company for servicing during the period 2000–2006. Although subjects were not informed that the data might be used for research, they were completely anonymous – the equipment does not store information that would enable subjects to be identified. Subjects will generally have been healthy, as the devices were not used for medical purposes. Few individuals had a BMI of less than 18 kg/m^2 (0.7%). Data were obtained on a total of 11,582 male and 12,044 female subjects 11,435 (Table 1).

The analyzers were returned from customers throughout the UK. Typically about 20–50 records are stored on each device and information from 322 devices was obtained.

2.2. Impedance measurements

Subject age and gender were input to the Bodystat analyzers, as were height and weight which were measured independently. The BIA method uses a non-invasive technique to measure the subject's body fat and fat-free mass. The subjects were given instructions to undertake the measurement in a state of normal hydration (no exercise or alcohol/caffeine consumption in the preceding 12 h and no eating or drinking in the preceding 4–5 h). Detailed instructions about electrode placements according to the manufacturer's manual were also provided. Two electrodes are placed on the right hand and two on the left foot to perform a whole body measurement[29] by passing a safe signal at a low 400 µA and a frequency of 50 kHz through the body. The results are displayed within seconds on a two line screen of the small portable hardware measuring device. The inter-machine reliability was excellent with 99% of the machines reading within 0.2% of a standard resistor (500 ohms). The intra-observer precision of impedance measurements in the same subjects under standard condition was <1%.[25] A series of validity and reliability studies have been undertaken (see Introduction and Discussion). The equations that were used to calculate percent body fat have not been released by the manufacturer.

2.3. Data analysis

Subjects were grouped into age groups for each age from 20 to 70 years in intervals of one year. Means and standard errors were calculated in the usual way. The four-way association between age, gender, BMI, and body composition was examined by tabulation, with subjects' age classified into decades. Patterns were sufficiently clear and consistent to make their statistical significance in this large data set beyond doubt. Multiple regression analysis (Statistical Package for the Social Sciences (SPSS) version 15; Illinois, USA) was also used to examine the effect of age, gender and gender–age interactions on BMI–% fat relationships. The basic model involved examining BMI–% fat relationship after adjusting for gender and age (model 1). This was extended to examine non-linearity of BMI–% fat relationship by including a quadratic term for BMI (BMI^2 in model 2). This was extended further by including an additional interaction terms (age–gender interaction and age–BMI interaction) in model 3. Visual inspection of the relationship between BMI and % fat was also made. The extent to which particular terms (such as polynomial terms for non-linearity, and product terms for interactions) improved the model fit was assessed by the statistical significance of these terms. However, with a large number of observations, terms with quite a small effect on the model can reach statistical significance. To further examine the BMI–fat relationships the raw impedance measurements obtained using the Bodystat machine were also analysed using an independently derived equation based on a reference multicomponent model of body composition obtained on a large sample of adults.[30]

3. Results

3.1. Body fat percentage, fat mass, and lean mass

Fig. 1 shows mean % body fat as a function of age and gender. The pattern is clearly one of a fairly steady increase from age 20 to 70 in both genders. The increase amounts to 2.4% (se 0.06%) and 1.9% (se 0.05%) per decade for females and males respectively if a linear trend is fitted. The mean becomes more variable after the age of 60 years due to the smaller subject numbers.

Fig. 2 shows that the increase in % body fat with age is predominantly due to a steady increase in fat mass and a smaller reduction in lean mass (fat-free mass) in older age groups. Fat mass increases by 1.9 (se 0.05) kg per decade (2.1 kg per decade in women and 1.8 kg per decade in males) when a linear trend is fitted. Lean mass declines as a percentage of total body mass in accordance with the increase in fat percentage. Fig. 2 shows how absolute lean mass changes with age in males and females. The pattern differs between genders. In females it remains fairly constant from 20 to mid forties, declines gradually until about 60 years, and then levels off. In males there is a slight increase during the early 20s, followed by a plateau until about 50 years, after which there is there is decline.

Table 1
Subject characteristics.

Age group (years)	Male					Female				
	N	Weight (kg)	Height (m)	BMI (kg/m^2)	% body fat	N	Weight (kg)	Height (m)	BMI (kg/m^2)	% body fat
18–19	323	76.4 ± 13.0	1.78 ± 0.07	24.2 ± 3.5	17.0 ± 8.1	313	65.6 ± 13.7	1.65 ± 0.06	24.0 ± 4.6	28.0 ± 8.0
20–29	2408	81.7 ± 13.8	1.79 ± 0.07	25.6 ± 3.9	19.0 ± 7.6	2839	66.3 ± 13.0	1.65 ± 0.07	24.3 ± 4.5	29.1 ± 8.1
30–39	2809	86.2 ± 14.7	1.78 ± 0.07	27.0 ± 4.2	21.8 ± 7.0	3375	69.1 ± 15.0	1.64 ± 0.06	25.6 ± 5.3	31.7 ± 8.4
40–49	2935	87.2 ± 14.0	1.78 ± 0.07	27.5 ± 4.0	23.6 ± 6.4	2844	70.7 ± 14.4	1.64 ± 0.06	26.3 ± 5.3	34.0 ± 8.4
50–59	2177	86.9 ± 13.1	1.77 ± 0.07	27.6 ± 3.8	24.9 ± 6.2	1863	70.7 ± 13.8	1.63 ± 0.06	26.7 ± 5.0	36.8 ± 8.3
60–69	754	85.1 ± 12.9	1.76 ± 0.07	27.5 ± 3.9	26.2 ± 6.7	670	69.7 ± 12.1	1.61 ± 0.06	26.8 ± 4.4	38.4 ± 8.3
70+	176	80.3 ± 11.0	1.74 ± 0.06	26.4 ± 3.1	26.6 ± 6.8	140	69.4 ± 13.1	1.60 ± 0.06	27.1 ± 4.9	40.0 ± 9.4
All groups	11,582	85.2 ± 14.1	1.78 ± 0.07	26.9 ± 4.1	22.5 ± 7.3	12,044	69.0 ± 14.1	1.64 ± 0.07	25.7 ± 5.1	32.8 ± 8.9

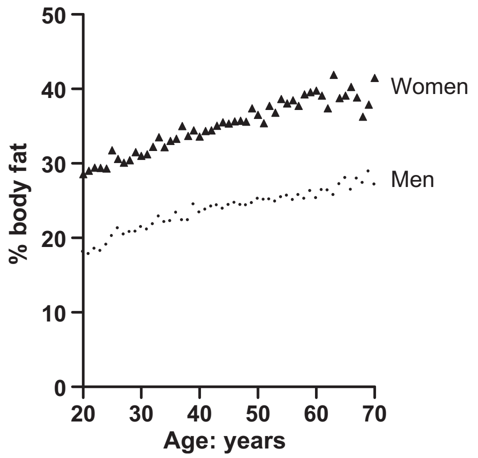

Fig. 1. Percent body fat as a function of age in men (smaller symbol – circle) and women (larger symbol – triangle).

3.2. Association with BMI

BMI is widely used as a proxy for fatness, with the well-known advantage of being easy to measure, and disadvantage of inability to distinguish between fatness and above average muscular development. The pattern of variability of BMI with % body fat can be seen in Fig. 3. It appears that the association is stronger at higher BMI. It is weaker in the BMI range 20–25 kg/m^2, a region in which a large proportion of the population occurs. The correlations between BMI and body fat in the ranges 18–25 kg/m^2 and 25–32 kg/m^2 are 0.21 and 0.38 respectively in males. The difference is less in females, being 0.38 and 0.40 in the same ranges.

3.3. Linear and non-linear components to the BMI–% fat relationship

Fig. 3 shows that the relationship between BMI and % fat is not strictly linear. The curvilinear relationship is less obvious if only subjects with a BMI less than 35 kg/m^2 are considered. Table 2 shows that in addition to the linear component there is a significant quadratic component. If only subjects with a BMI $<$ 35 kg/m^2 were used in the analysis, the quadratic component (model 2) is no longer significant ($p = 0.069$).

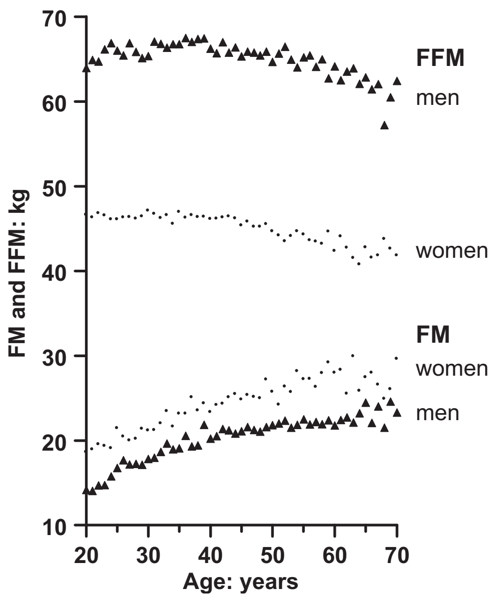

Fig. 2. Fat mass (FM) (kg) and fat-free mass (FFM) (kg) as a function of age in men and women.

3.4. Effect of age

Like % body fat, BMI also increases with age. In view of the patterns of change in lean mass, we can examine whether the association changes with age. It is apparent from Fig. 4 that it does. At a fixed BMI, body fatness is greater in older subjects. This effect is greater at lower BMI. The independent effect of age is also shown using regression analysis (Table 2). Thus at a fixed BMI in a person aged 70 years there is 5.4% (model 2 in Table 2) or 5.6% (model 1, Table 2) more fat than in a person aged 30 years with the same BMI. There appears to be a small gender–age interaction (model 3).

3.5. Graphical presentation of independent effects of BMI and age on % body fat

Fig. 4 is used to illustrate three points. First, at a given BMI and age, % body fat is higher in females than males. Second, at a fixed age, % body fat shows a large overall increase with BMI. Third, at a fixed BMI, % body fat shows an increase with age.

3.6. Comparison with % fat obtained using the equation of Sun et al.[30]

When the impedance values obtained with Bodystat were applied to the equation of Sun et al. for whites (Sun) (the equation for blacks is virtually identical) the % fat was strongly related to % fat obtained by the Bodystat equation ($r = 0.901$):

$$\%\text{fat (Bodystat)} = -1.314 + 1.005\,\%\text{fat (Sun)}$$

The standard error for %fat (Sun) in the above equation is 0.003. When % fat (Sun) was used in models 1 and 2, instead of %fat (Bodystat), the overall model predictions were broadly similar ($r^2 = 0.66$ (Bodystat) and $r^2 = 0.64$ (Sun)). Using the Sun equation, there was a large significant gender effect and also significant BMI and BMI^2 (curvilinear relationship) effects, which were stronger than those obtained when %fat (Bodystat) was used in the model. With model 3 the following equation was generated:

$$\begin{aligned}\%\text{fat (Sun)} = {} & -32.515 + 12.409\,\text{gender} + 3.306\,\text{BMI} \\ & - 0.030\,\text{BMI}^2 - 0.006\,\text{Age} + 0.033\,\text{Age*gender} \\ & - 0.001\,\text{Age*BMI}\end{aligned}$$

where gender = 0 for men (i.e. for men this term is ignored) and 1 for females. The partial eta squared for gender was 0.062 ($p < 0.001$), BMI, 0.124 ($p < 0.001$) for BMI^2, 0.051 ($p < 0.001$), 0.000 for age ($p = 0.682$), for Age * gender interaction 0.002 ($p < 0.001$) and for Age * BMI interaction $<$0.0005 ($p = 0.026$).

4. Discussion

The changes in body composition with age have been widely studied, and so we cannot claim novelty for some of the results we have presented in this paper. The contribution we have made is to verify the patterns that other studies have shown by using a well-tested method on an exceptionally large sample of adults spanning a wide range of age and BMI. That the patterns in our data in the UK are similar to those found elsewhere gives us confidence that the

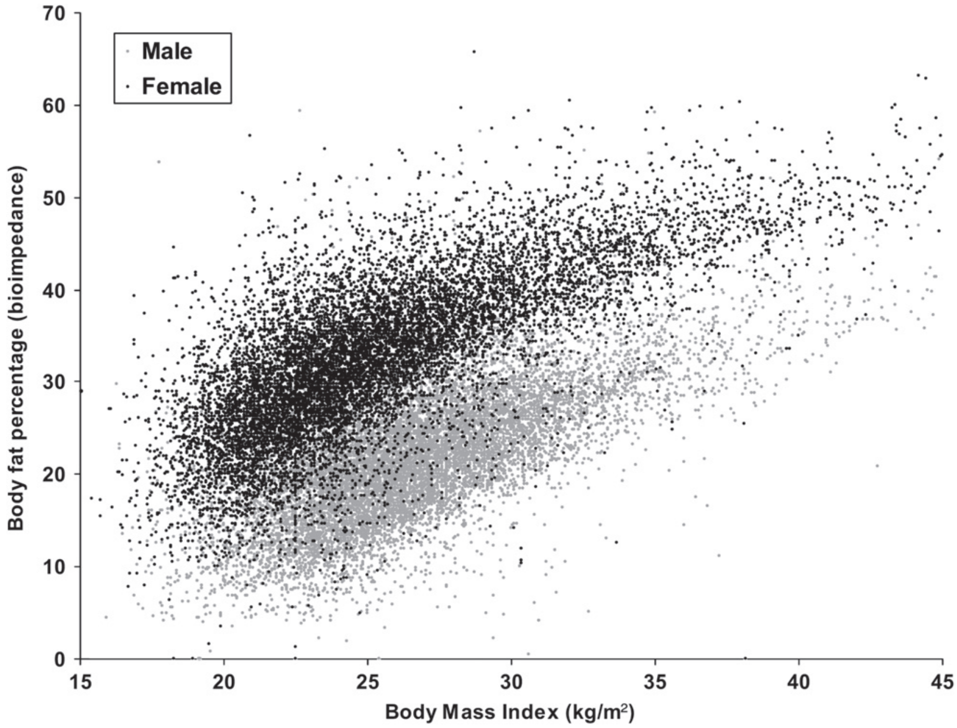

Fig. 3. Distribution of BMI as a function of percent body fat in men (grey) and women (black).

aspects of the BMI–body composition we describe are also true of the population in general. The data also help resolve some uncertainties about BMI–% fat relationships.

The conclusions depend on the validity of the Bodystat BIA system for measuring body composition especially % body fat. This was examined using pre-existing studies in lean, overweight and obese individuals from a series of separate population samples. Compared to DXA, Bodystat was found to give a 2% lower figure for % body fat in a group of 28 mostly non-obese men and women, with no significant increase in bias (when each gender was analysed separately and together) as the magnitude of the measurement increased (mean of two methods).[22] Another DXA study, involving a group of 56 subjects with 10–40% fat, showed no overall bias with Bodystat (<0.1%),[25] and no increase in bias as % body fat increased. Compared to deuterium dilution, and the 3 compartment model, Bodystat was found to show little bias (≤1% bias in % body fat) in group of mostly lean[22] and obese women.[23] In contrast, in a group of mostly lean men and women Bodystat estimates of % body fat were found to be higher than results obtained by densitormetry,[22] whilst the reverse was found in a group of obese women.[23] Although within each study group no significant change in bias was found in men or women as the magnitude of the measurement increased[22,23] (the same applied to other reference techniques), there was a tendency for Bodystat to underestimate % body fat in lean subjects relative to densitometry (and some other reference methods) in lean subjects in some studies, and overestimate it in obese subjects in other studies.[22–24] A similar conclusion was reached when % fat obtained by Bodystat was compared to hydrodensitometry in a group 50 men and women were examined together, rather than separately (although the men and women (18–38% fat) formed almost completely different populations as far as % fat was concerned (2–23% fat versus 18–38% fat respectively)).[31] The potential relevance of this to our conclusion about BMI–% fat relationship is discussed below.

Other studies reported correlations between reference methods and Bodystat for measurements of % body fat. In a group of 61 women with a mean BMI of 26.3 kg/m^2 the correlation between % body fat measured by Bodystat and air displacement plethysmography was found to be 0.91 (Bodystat giving about 2% lower values than air displacement plethysmography).[27] The same correlation coefficient was between % fat measured by Bodystat and DXA in a group of 61 overweight and obese women (in whom Bodystat was

Table 2
Regression analysis for change in percent body fat with BMI (kg/m^2), age (years), and gender.

	Regression coefficient or intercept	SE	p	Partial eta squared
Model 1				
Intercept	−13.510	0.258	<0.001	0.001
+Female	11.881	0.073	<0.001	0.521
BMI	1.129	0.008	<0.001	0.452
Age	0.140	0.003	<0.001	0.093
Model 2				
Intercept	−20.168	0.098	<0.001	0.001
+Female	12.008	0.075	<0.001	0.518
BMI	1.607	0.054	<0.001	0.036
BMI^2	−0.008	0.001	<0.001	0.003
Age	0.136	0.003	<0.001	0.087
Model 3				
Intercept	−21.420	0.952	<0.001	0.021
+Female	10.269	0.229	<0.001	0.077
BMI	1.676	0.057	<0.001	0.035
BMI^2	−0.008	0.001	<0.001	0.003
Age	0.180	0.017	<0.001	0.005
Age * gender interaction				
+Female	0.044	0.005	<0.001	0.003
Age * BMI interaction	−0.002	0.001	<0.001	0.001

Units: BMI, kg/m^2; Age, years; Gender, male = 0 (referent), female = 1.

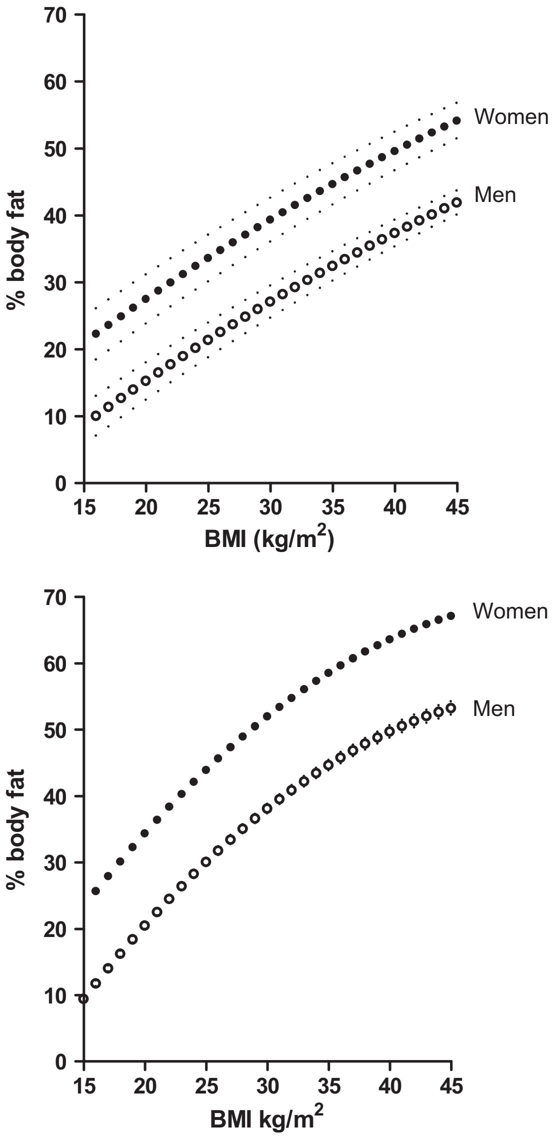

Fig. 4. Relationship between BMI (kg/m^2) and percent body fat in men and women (fitted curves). *Upper graph* (Bodystat system): shows the results of 45 year old women (closed circles) and men (open circles). The dotted lines above and below these symbols relate to 65 and 25 year old subjects respectively. *Lower graph* (raw impedance data obtained by Bodystat applied to the equation of Sun et al.[30]): shows the results for 45 year old men and women with dotted lines hidden behind the main symbols.

reported to perform better than two other BIA machines and skinfold measurements).[26] Validation studies in subjects with disease are not considered further here, especially since some of them have examined validity of Bodystat with respect to lean body mass and water spaces rather than % body fat.[32,33]

We have been able to make a detailed investigation of the association between % body fat and BMI. Overall the amount of variation in body fat that is explained by BMI, when age is accounted for, is 44% in men and 58% in women. Thus we have shown that the association is not especially good. This is particularly so when BMI is less than 25 kg/m^2 (as might be expected for the curvilinear relationship) particularly in men, and have demonstrated that the BMI–% fat association depends on age. Because BMI is easy to measure, it is unlikely that it will be replaced by any other measures of fatness for widespread use, especially since it can predict % body fat fairly well when the BMI values are greater than about 27 kg/m^2. It is the variation among those with BMI < 27 kg/m^2 which is more poorly associated with % body fat that is of greater concern.

The study also addresses some controversial issues in body composition. One of these is whether the BMI–% body fat relationship is linear or curvilinear. Our findings are in agreement with a study in the USA which showed that it is curvilinear (quadratic), especially at high BMI values. In contrast, another study from the USA[10] found the relationship was linear rather than quadratic. However, in this last study virtually all the subjects had a BMI of <35 kg/m^2. In the present study and that of Jackson et al.[9] the quadratic effect was obvious from the influence of individuals with BMI of 35 kg/m^2 or more. This was also the case for women, although not so obvious in men, in another body composition study from the USA in which half of the subjects had a BMI greater than 35 kg/m^2.[19] Although Bodystat has validity relative to other reference body composition techniques, a between study comparison using certain reference techniques (e.g. hydrodensitometry), suggest that Bodystat might underestimate % body fat in lean subjects and overestimate it in obese subjects. If that were the case in our population, so that the % body fat was in reality greater than that reported by the Bodystat in lean subjects and lower than that reported by Bodystat in obese subjects, the curvilinear nature of the BMI–% body fat relationship might also be altered.

To further examine the validity of the findings we used the raw impedance values obtained in this study and applied them to the equation of Sun et al.[30] which was based on a large multicomponent model of body composition involving measurements of total body water using deuterium dilution, body density based on hydrodensitometry and bone mineral content based on dual energy X-ray absorptiometry. It involved measurements obtained on a large sample of subjects from five independent research centres in the USA. The curvilinear (quadratic component) was not only demonstrated with the Sun equation but it was also more prominent than that obtained with the Bodystat system (Fig. 4; lower graph). Although this supports the conclusion of the Bodystat analysis some caution should be exercised when applying data of impedance obtained by one type of machine to an equation to resistance data obtained by another (RJL machine). However a very strong relationship has been reported between raw measurements obtained by the Bodystat and RJL machines (r = 0.996).[25] In addition, Webster et al.[34] who undertook measurements of body composition in lean and obese women using the water dilution technique, argued from an analysis of their data and from theoretical considerations that the BMI–% body fat relationship was curvilinear.

Two further issues of concern are addressed with the Bodystat analysis. The first is the magnitude of the effect of age on BMI–% body fat relationships, which has been reported to vary by more than two-fold. The coefficient for age (1.4% increase in % body fat per decade of age in models 1 and 2 (Table 2)) is essentially the same as those obtained by Jackson et al.[9,14] (1.4% per decade[9] or 1.3% per decade reported earlier[14]). It is lower than that reported by Deurenberg et al.[11] (2.3 (se, 0.1) % fat per decade) for men and women, and higher than that reported by Gallagher et al.[10] (0.96 (se, 0.19) % fat per decade) for white women. Thus, the data from this study (1.4% fat per decade) are intermediate between those obtained by other studies (although application of the raw Bodystat data into the Sun equation[30] demonstrate only a trivial age effect). Second, it can be suggested that men who have more muscle, and hence greater potential for muscle loss with aging, would require additional tissue, such as fat, to maintain a given BMI. If this were the case there would be an age–gender interaction. Whilst a significant interaction was observed in this study the effect was opposite to that predicted i.e. the age effect was greater in females than males (by 0.4% per decade). In the study of Jackson et al. 2002[9] the coefficient for age (1.4% fat per decade) was the same for men and women, whilst in the study of Gallagher et al.[10] the coefficient for age in white men was two-fold greater than in white women (1.77 (se, 0.2)% per decade versus 0.96 (se, 0.19)% per decade). The reasons for these discrepancies in these cross sectional studies are unknown but they could be due to the use of different body composition methodology as well as biological differences in the characteristics of the study populations. These include differences in the age and BMI distribution and the possibility that loss of muscle may be compensated by an increase in other components of the fat-free body. For example, a decrease in the extra-cellular fluid relative to intracellular water (an indicator of body cell mass) is known to occur with age, especially in older age.[35] A small increase in the hydration fraction of the fat-free body is also thought to occur with aging[36]. The age-BMI interaction had a negligible effect on the prediction of % body fat.

We recognise that our study has a major limitation: we had no control over the selection of the subjects. Because of this, we have not drawn any conclusions about body composition distribution or averages in the UK population. What we have assumed is that the pattern of association between body composition and other subject characteristics is representative. We have no way of verifying this assumption, but we note that the distribution of BMI between underweight (BMI <18.5 kg/m^2), normal weight (BMI 15.5–24.9 kg/m^2), overweight (BMI 25.0–29.9 kg/m^2) and obese (BMI ≥ 30 kg/m^2) categories – 1.2%, 43.5%, 38.0% and 17.3% respectively – is not very different from the mean of the annual results (2000–2006) of the Health Survey for England[37] (1.5%, 36.8%, 38.6% and 23.1%), which involved collection of data over the same period of time as our study (2000–2006). Another limitation is that the study is based on cross sectional observations and not longitudinal observations and the measurements were made by a large number of different observers who followed the instructions provided by the manufacturers. The machines had excellent accuracy and reproducibility against a reference resistor, and their accuracy and reliability, when used in separate groups of lean and obese subjects, has been discussed above. Yet another limitation is that bioelectrical impedance is not generally considered to be as good a reference as the classic body composition techniques (such as hydrodensitometry or water dilution techniques) or multicomponent models based on measurements obtained by several reference body composition techniques. However, in epidemiological studies some accuracy is sacrificed for simplicity, acceptability and rapid data acquisition which in combination allow studies with large sample size and more power to be undertaken.

Given that that BMI has problems as an indicator of body composition what recommendations can we make? We suggest the following three:

- While BMI is a quick and easy measure that the general public can understand and use, a more direct measurement of body composition should become more of a routine procedure in research studies investigating its association with health. Any demonstrable superiority of body composition measurements over BMI in predicting health risks would be particularly important. For example a Swedish study showed that body fat measured by BIA in women aged 45–75 years was a better predictor of mortality than BMI.[38] Another study involving Swiss and German patients admitted to hospital found that indices of body composition measured by impedance were better than BMI in predicting length of hospital stay.[39]
- Where BMI is routinely used it should be remembered that a given value implies greater body fat in older subjects, and that the threshold for recommending weight management (weight reduction for overweight subjects or weight gain for underweight individuals) should perhaps be lower.
- BMI should be considered a particularly poor indicator of body fat in men whose BMI is less than 25 kg/m^2.

Conflict of interest

ME and GWH have no conflict of interest. SM (Managing director of Bodystat Ltd) provided the data collected by the Bodystat bioimpedance machines to ME and GWH, both of whom analysed the data and drafted the paper.

Author agreement

All authors agreed on this version of the paper. SM collected the data and some references, and the other two authors drafted the paper.

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