International Journal of Obesity (2002) 26, 953–960
 0307–0565/02 $25.00
www.nature.com/ijo

PAPER

Fat-free mass index and fat mass index percentiles in Caucasians aged 18–98 y

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OBJECTIVE: To determine reference values for fat-free mass index (FFMI) and fat mass index (FMI) in a large Caucasian group of apparently healthy subjects, as a function of age and gender and to develop percentile distribution for these two parameters.
DESIGN: Cross-sectional study in which bioelectrical impedance analysis (50 kHz) was measured (using tetrapolar electrodes and cross-validated formulae by dual-energy X-ray absorptiometry in order to calculate FFMI (fat-free mass/height squared) and FMI (fat mass/height squared).
SUBJECTS: A total of 5635 apparently healthy adults from a mixed non-randomly selected Caucasian population in Switzerland (2986 men and 2649 women), varying in age from 24 to 98 y.
RESULTS: The median FFMI (18–34 y) were 18.9 kg/m^2 in young males and 15.4 kg/m^2 in young females. No difference with age in males and a modest increase in females were observed. The median FMI was 4.0 kg/m^2 in males and 5.5 kg/m^2 in females. From young to elderly age categories, FMI progressively rose by an average of 55% in males and 62% in females, compared to an increase in body mass index (BMI) of 9 and 19% respectively.
CONCLUSIONS: Reference intervals for FFMI and FMI could be of practical value for the clinical evaluation of a deficit in fat-free mass with or without excess fat mass (sarcopenic obesity) for a given age category, complementing the classical concept of body mass index (BMI) in a more qualitative manner. In contrast to BMI, similar reference ranges seems to be utilizable for FFMI with advancing age, in particular in men.
International Journal of Obesity (2002) **26,** 953–960. doi:10.1038/sj.ijo.0802037

Keywords: BMI; fat-free mass; fat mass; body composition; gender; aging

Introduction

In the last decade a dramatic increase in overweight and obesity has been reported in both developed and underdeveloped countries.[1] Associated with this excess of body weight and body fat, there is an increased risk of developing heart diseases, diabetes and cancer, so that obesity was declared a disease more than 15 y ago.[2]

Prevention of weight gain, which ultimately leads to obesity, is becoming a priority in public health policy. The degree of obesity is simply defined in most epidemiological studies by means of the body mass index (BMI).

Nowadays, BMI has progressively replaced the concept of 'ideal body weight' since the latter had the drawback of being dependent upon reference standards of body weight and height from populations, which slowly changed from decade to decade and also varied according to which reference standard was used (for example, Metropolitan Life Insurance Tables). Potential limitations of the BMI concept have been outlined[3] and have been the object of several exchanges of letters among scientists.[4–6]

The number of publications using the BMI as an index of obesity is large and it has been described in a wide variety of populations.[7–17]

Reference standards for the 'normality' of BMI have been defined to classify various degrees of overweight and obesity, but universal cut-off points have been challenged.[18] Similarly, low levels of BMI have been used to classify chronic energy deficiency.[19]

The major shortcoming of the BMI is that the actual composition of body weight is not taken into account: excess body weight may be made up of adipose tissue or conversely muscle hypertrophy, both of which will be judged

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Received 29 June 2001; accepted 11 March 2002

as 'excess mass'. On the other hand, a deficit of BMI may be due to a fat-free mass (FFM) deficit (sarcopenia) or a mobilization of adipose tissue or both combined.[20]

The concept of fat-free mass index (FFMI) and fat mass index (FMI), in analogy to the BMI but using a two compartment model, merits a reappraisal and appears to be of interest in the classification of overweight/overfat patients (respectively underweight/underlean).

The partitioning of BMI into FFMI and FMI is obviously not possible without associated measurements of body composition. Note that the original idea of calculating the FFM and fat mass (FM) indexes, in analogy to the BMI, was proposed several years ago.[21] The potential advantage is that only one component of body weight, ie FFM or FM, is related to the height squared. Surprisingly, these indexes have not found a wide application yet, probably because appropriate reference standards have yet to be defined. By determining these indexes, quantification of the amount of excess (or deficit) of FFM, respectively FM, can be calculated for each individual.

In the present study, we have attempted to describe, in a large number of apparently healthy Caucasian subjects, the percentile values for FFMI and FMI as a function of gender and age.

Subjects and methods

To determine reference values for a large subject population, 5635 apparently healthy adults (2986 men and 2649 women), aged 24–98 y, were recruited in the towns of Geneva and Lausanne (French speaking part of Switzerland). The anthropometric data and number of subjects per age group is shown in Table 1. All subjects were ambulatory Caucasians who had no known pathology or physical handicap. Smoking was not considered as an exclusion criteria. Due to the heterogeneity of the population in these cosmopolitan cities, about one-third of the individuals were of non-Swiss origin, so that the present sample may be more representative of an European population than people of strictly Swiss nationality.

The investigation was approved by the Geneva University Hospital Ethics Committees. All subjects volunteered for the study.

Calculation of FFM and FM indexes

The FFM and FM indexes are equivalent concepts to the BMI, as shown in the following definition:

$$\text{FFMI} = \frac{\text{fat-free mass}}{\text{height}^2}\left(\frac{\text{kg}}{\text{m}^2}\right)$$

$$\text{FMI} = \frac{\text{fat mass}}{\text{height}^2}\left(\frac{\text{kg}}{\text{m}^2}\right)$$

Note that, mathematically, BMI (kg/m^2) = FFMI (kg/m^2) + FMI (kg/m^2).

Measurements of fat-free mass and fat mass

Body height was measured to the nearest 0.5 cm and body weight to the nearest 0.1 kg on a balance beam scale (Seca Corp. Scale, Germany). Resistance and reactance were measured by bioelectrical impedance analysis (BIA) generators and used to first mathematically derive FFM and FM as described previously.[22–27]

The following formula was used: $V = \rho \times ht^2/R$ in which the conductive volume (V) is assumed to represent FFM, ρ is the specific resistivity of the conductor, height (ht) is assumed to represent the length of the conductor, and (R) is the whole-body resistance.

All BIA measurements were performed 2–3 h after the last meal.

Measurements of numerous participants involved in 'fun runs' were made prior to their race, to avoid changes in hydration, skin temperature, plasma electrolyte concentration and glycogen stores.[28]

Table 1 Anthropometric and body composition characteristics of healthy Caucasian adults

Age		*18–98 y*		*18–34 y*	*35–54 y*	*55–74 y*	*75–98 y*
Men	*n*	2986		1088	1323	448	127
Height	cm	175.7±7.1	(150–203)[a]	177.9±6.6	175.6±6.8**	172.4±6.6**	169.3±7.5**
Weight	kg	74.2±9.2	(47–117.6)	73.3±8.7	74.7±9.2**	75.1±10.2	72.2±8.7*
Body mass index	kg/m^2	24.0±2.7	(17.4–40.1)	23.1±2.3	24.2±2.5**	25.3±3.1**	25.2±3.0
Fat-free mass	kg	59.1±5.6	(38.9–81.6)	59.9±5.4	59.4±5.5*	57.7±5.5**	53.6±5.5**
Fat mass	kg	15.0±5.5	(4.4–49.1)	13.4±4.8	15.2±5.3**	17.5±6.2**	18.6±5.2*
Fat mass	%	19.9±5.4	(6.8–42.7)	17.9±4.7	20.0±5.1**	22.7±5.6**	25.4±5.1**
Women	*n*	2649		1019	1033	386	211
Height	cm	163.3±6.8	(139–186)	165.9±6.2	163.5±6.0**	160.1±6.1**	156.3±6.6**
Weight	kg	60.0±8.8	(37.5–127.4)	58.6±7.5	59.6±8.6**	63.9±10.3**	61.8±10.2**
Body mass index	kg/m^2	22.5±3.3	(16.0–47.1)	21.3±2.4	22.3±2.9**	24.9±3.8**	25.3±4.2
Fat-free mass	kg	42.4±4.4	(26.6–67.2)	42.7±4.0	43.0±4.1	42.1±4.7**	38.8±4.7**
Fat mass	kg	17.6±6.2	(4.8–60.2)	15.9±4.7	16.6±5.7*	21.8±6.9**	22.9±7.0*
Fat mass	%	28.7±6.4	(11.6–53.7)	26.6±5.0	27.3±5.7**	33.4±6**	36.4±6.4**

ANOVA comparison between age groups *$P < 0.05$, **$P < 0.001$.
[a]Range

Whole-body resistance (R) was measured with four surface electrodes placed on the right wrist and ankle, as previously described.[29] Short-term reproducibility of resistance measurements indicates coefficients of variation ranging from 1.8 to 2.9%.[26,27]

Briefly, the principle was based on the application of an electrical current of 50 kHz and 0.8 mA produced by a generator (Bio-Z2®, Spengler, Paris, France) and applied to the skin using adhesive electrodes (3M Red Dot T, 3M Health Care, Borken, Germany) with the subject lying supine.[30] The skin was cleaned with 70% alcohol.

In order to permit inclusion of a large number of subjects, several BIA instruments, which were cross-validated, were used. The limit of tolerance between instruments was $\pm 5\Omega$ at 50 kHz using a calibration jig. *In vivo* comparative measurements were also performed. The Bio-Z2® generators were cross-validated at 50 kHz against the RJL-109® and 101® analyzers (RJL Systems Inc. Clinton Twp, MI, USA) and against the Xitron 4000B® analyzer (Xitron Technologies Inc., San Diego, CA, USA). No substantial difference ($P > 0.05$) was found between the Xitron, the Bio-Z instrument and the RJL 101 device. Earthman *et al*[31] have also reported no significant differences between the Xitron 4000B and the RJL 101 devices.

All investigations were subsequent to a standardized training in order to minimize errors due to multiple operators.

FFM derived from BIA has been validated previously[32] against dual-energy X-ray absorptiometry (DXA; Hologic QDR-4500® instrument, Hologic Inc. Waltham, MA, USA) in 343 apparently healthy subjects between 18 and 94 y with a BMI ranging from 17.0 to 33.8 kg/m^2.

The following multiple regression equations were found:

$$\begin{aligned}\text{FFM} = &-4.104 + (0.518 * \text{height}^2/\text{resistance}) \\ &+ (0.231 * \text{weight}) + (0.130 * \text{reactance}) \\ &+ (4.229 * \text{sex}(\text{men} = 1, \text{women} = 0))\end{aligned}$$

DXA-measured FFM was 54.0 ± 10.7 kg. BIA-predicted FFM was 54.0 ± 10.5 kg, bias 0.03 ± 1.7 kg, $r = 0.986$, s.e.e. $= 1.72$ kg. In addition, we also compared the results of the Bio-Z_2 device with DXA values in 250 of the 343 subjects included in the above study (unpublished data). Using the above BIA equation the FFM measured Bio-Z_2 was 54.1 ± 10.5 *vs* 54.2 ± 10.7 kg assessed by DXA. The mean difference between DXA and Bio-Z_2 averaged 0.13 ± 1.7 kg; $r = 0.99$, s.e.e. 1.6 kg, unpaired t-test $P = 0.22$, which is not different from the bias between DXA and the Xitron device.

Statistics

The statistical analysis program StatView, version 5.0 (Abacus Concepts, Berkeley, CA, USA) was used for statistical analysis. The results are expressed as mean ± standard deviation (x ± s.d.). Age- and sex-specific percentile distributions were calculated for each of the following parameters: FFMI and FMI. The data were stratified by steps of 10 y as reported for BMI and anthropometric data in NHANES study[33,34] and Canada.[35] The ith percentile (Pi) was the value at or below which there was i% of the sample. For example, the 50th percentile (P50) was the value at or below which there were 50% of the observations for a given variable. Given a total of n ordered values for each parameter ($X_1, X_2, X_3, \ldots X_n$) the ith percentile (Pi) in any of the calculated distribution was computed as follows: $P_i = (1 - A)(X_b) + (A)(X_b + 1)$, using the Statview® 4.1 statistical program.

The differences among age groups were analyzed by analysis of variance (ANOVA) with Fisher protected least significant difference comparison.

Results

Table 1 presents the anthropometric characteristics of the men and women. It is apparent that in both genders, the mean BMI of the apparently 'healthy' elderly individuals (25.2 kg/m^2 in males and 25.3 kg/m^2 in females) was higher as compared with the young individuals, but still on the borderline of the 'normal' reference range defined in young individuals.

The results of the FFMI categorized by gender and age are given in Table 2, where they are distributed into different percentiles values. In the young male subjects, FFMI was

Table 2 Percentiles values for FFM and FM index in men and women by different age categories

	P5		*P10*		*P25*		*P50*		*P75*		*P90*		*P95*	
Age (y)	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
Fat-free mass index (kg/m^2)														
18–34	16.8	13.8	17.2	14.1	18.0	14.7	18.9	15.4	19.8	16.2	20.5	17.1	21.1	17.6
35–54	17.2	14.4	17.6	14.7	18.3	15.3	19.2	15.9	20.1	16.7	21.1	17.5	21.7	18.0
55–74	17.0	14.1	17.6	14.6	18.4	15.4	19.4	16.2	20.3	17.4	21.1	18.4	22.1	19.0
>75	16.6	12.9	16.9	13.7	17.6	14.7	18.5	15.9	19.4	17.0	20.9	18.1	21.2	18.7
Fat mass index (kg/m^2)														
18–34	2.2	3.5	2.5	3.9	3.2	4.6	4.0	5.5	5.0	6.6	6.1	7.8	7.0	8.7
35–54	2.5	3.4	2.9	3.9	3.7	4.8	4.8	5.9	6.0	7.3	7.2	8.8	7.9	9.9
55–74	2.8	4.5	3.4	5.4	4.3	6.5	5.7	8.3	7.2	10.3	8.4	12.0	9.3	13.5
>75	3.7	4.9	4.3	5.6	5.2	7.5	6.4	9.3	7.6	11.4	9.0	13.5	10.1	14.3

around 19 kg/m^2 (P50 = 18.9 kg/m^2, range 5th–95th percentile: 16.8–21.1 kg/m^2) and did not change significantly in the higher age category. In young women, FFMI was around 15 kg/m^2, ie 20% lower than in males (P50 = 15.4 kg/m^2, range 5th–95th percentile: 13.8–17.6 kg/m^2). FFMI in women tended to be modestly but significantly higher ($P \leq 0.001$) in the advanced age category.

The FMI results are presented in Table 2, where they are classified into different percentiles: the average FMI for young men was 4.0 kg/m^2 (range 5th–95th percentile: 2.2–7.0 kg/m^2) and was higher by about 2 units in the higher age category. In young women, FMI averaged 5.5 kg/m^2 (range 5th–95th percentile: 3.5–8.7 kg/m^2) ie 38% higher than in males, with a significantly greater value ($P \leq 0.0001$) of almost 4 units in the advanced age category.

An overview of the effect of age and gender on FFMI and FMI values is given in Figures 1 and 2.

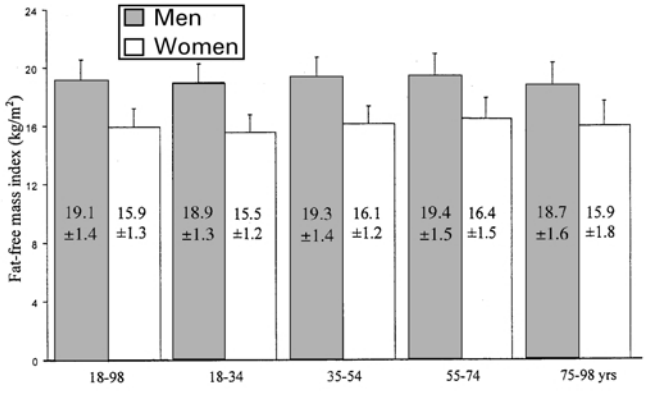

Figure 1 Fat-free mass index (FFMI) in men ($n = 2986$) and women ($n = 2649$) by age category. Mean ± s.d.

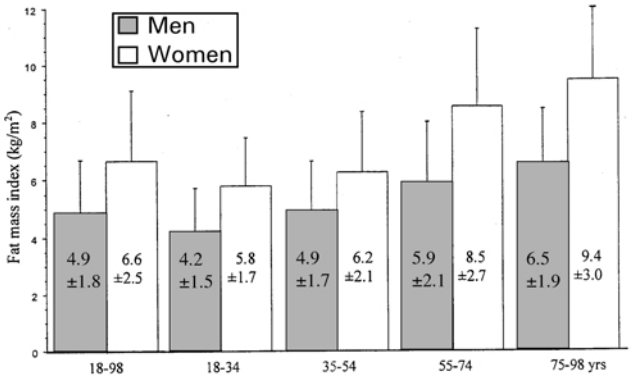

Figure 2 Fat mass index (FMI) men ($n = 2986$) and women ($n = 2649$) by age category. Mean ± s.d.

Table 3 Fat-free mass index (FFMI) and fat mass index (FMI) for the 25th and 75th percentile and various BMIs in apparently healthy Caucasian adults[a] aged 18–98 y

		Percentiles		*BMI (kg/m^2)*		
		P25	*P75*	*18.5*	*20.0*	*25.0*
Men						
FFMI	kg/m^2	18.2	20.0	16.7[a]	17.5[a]	19.8[a]
FMI	kg/m^2	3.5	5.9	1.8[a]	2.5[a]	5.2[a]
Women						
FFMI	kg/m^2	15.0	16.6	14.6[a]	15.1[a]	16.7[a]
FMI	kg/m^2	4.9	7.8	3.9[a]	4.9[a]	8.3[a]

[a]FFMI and FMI predicted from the following regression equations: *for FFMI prediction*, Men $y = 4.809 + 0.773^* x - 0.007^* x^2$; $r^2 = 0.619$, $P < 0.001$; women $y = 7.127 + 0.459^* x - 0.003^* x^2$; $r^2 = 0.606$, $P < 0.001$; where y is the FFMI (kg) and x is BMI (kg/m^2). For FMI prediction: Men $y = -4.74 + 0.222^* x + 0.007^* x^2$; $r^2 = 0.772$, $P < 0.001$; women $y = -7.12 + 0.54^* x + 0.003^* x^2$; $r^2 = 0.885$, $P < 0.001$; where y is the FMI (kg) and x is BMI (kg/m^2).

Discussion

Potential use of FFMI and FMI

Up to now, reference ranges for FFMI and FMI have not been clearly defined, at least in a large group of apparently healthy individuals. It is proposed that reference values may be useful, in a clinical setting or in field surveys, for comparative purposes in the evaluation of the nutritional status and body composition of patients with excess energy stores (such as obesity) on the one hand or deficit of muscle mass (such as in wasting disease) on the other hand.

The concept of FFMI has been previously described in adults and elderly individuals, as an indicator of nutritional status[21,36] as well as in chronic obstructive pulmonary disease patients.[37] The size of the present sample is larger than these previous studies and includes the effect of gender and age, bracketing a large age range in adulthood.

Partition of BMI

Considering that BMI is the sum of FFMI + FMI, an increase (or a decrease) in BMI could be accounted for by a rise (or a drop) in one component, in the other or in both components. Note that, for a given BMI, if FFMI increases then FMI should decrease, since, at a constant BMI, there is an inverse mathematical relationship between the two.

Therefore, the advantage of the combined use of these indices is that one can judge whether the deficit or excess of body weight is selectively due to a change in FFM *vs* FM or both combined. For example, an individual of 1.85 m and 100 kg has a BMI of 29.2 kg/m^2 and would be judged as largely overweight and even borderline obese. This would be true if his FMI is higher than the reference values and conversely if his FFMI is not simultaneously elevated.

Expression of FFM

An issue which has plagued nutritionists and body composition specialists is the expression of body composition results when inter-individual comparison are made: comparison in absolute value (kg) *vs* in relative value (ie percentage of body weight) or normalized value for 'size' (ie typically height squared in FFMI concept or occasionally adjustment for body surface area).

Since FFM is related to height, it seems inappropriate to give, for any individual, a cut-off point of FFM in absolute value (kg) below which FFM is judged as 'low'. For example, a short individual would be penalized since his absolute FFM is expected to be lower than that of a tall individual. Indeed a healthy and well-nourished young man would have a FFM expressed in absolute terms virtually the same as that of a similarly aged but taller individual suffering from protein-energy malnutrition.[21]

Bartlett *et al*[36] examined the relationship of FFM-to-height ratio (not height squared, which is not strictly equivalent to the FFMI) in 1103 people aged 6–86 y and confirmed the potential interest of an index related to height. We have chosen percentile values for evaluating the relative excess FM *vs* deficit of FFM. However, expressing the percentage deficit (or excess) with regard to the mean value (or median value, P50) would also be possible, in particular when the subjects are below P5 or above P95.

Effect of aging

As expected, FMI were significantly higher in elderly subjects as compared to younger ones. Previous results confirmed the evolution of the index with age found in the present study in men but not in women, in whom FFM index was found to be slightly but significantly higher after 60 y of age.[36] The cross-sectional nature of these studies may explain this discrepancy.

Since body weight increases with aging in industrialized countries, BMI requires an adjustment for age. This is not the case with FFMI, since the increase in body weight observed with aging in industrialized countries allows the net decrease in FFM accompanying aging to be partly offset. This is observed even when body weight is constant over the years. During aging, the weight gain is mostly explained by a gain in body fat, but this is linked to a slight rise in FFM.

Forbes[38] stated that weight gain of about 2 kg per decade was required to counteract the loss of FFM with aging. This corresponds to an increase in BMI slightly lower than 1 unit. During menopause and aging[39,40] changes in FFM and FM are not adequately picked up by changes in BMI since, as explained above, the two components of BMI (FFMI and FMI) can vary in divergent directions, the former increasing while the latter may be decreasing.

It is of interest that FFMI remained relatively constant with aging, at least in men, so that this does not require an age adjustment in the reference value, as does BMI.

Statistical and methodological shortcomings and bias

The inaccuracy and imprecision of height measurement among investigators may constitute a bias, in particular in elderly individuals due to posture and orthopedic factors. Obviously the commonly observed decline in height with aging constitutes a confounding factor for the calculation of BMI, FMI and FFMI. Since height naturally declines with aging, BMI, FFMI and FMI are expected to increase more with aging than without this confounding effect.

Although our volunteer subjects were (by design) not randomly selected, we feel that they are fairly representative of the population in terms of median BMI for both gender. The median BMI was 23.9 kg/m^2 for men and 22.1 kg/m^2 for women in the present study, compared to a median BMI of 25.3 kg/m^2 for men and 23.0 kg/m^2 for women in the randomly selected population, aged 40–59 y in the City of Geneva.[41] The average BMI would be expected to be lower in the present study because 40% of men and 30% women were <40 y, a greater proportion than in the above study.

Some obese subjects were included in the present group since they were judged 'apparently healthy' at the time of the measurement since no health problems were diagnosed and no recent medical treatment was reported.

The results of FFMI as a function of gender and age could be challenged by the limitation in the methods used to assess body composition in the present study. In a clinical setting, BIA constitutes a useful non-invasive and quick bedside tool for estimating FFM. This method allowed generation of the large sample size in the present study. The formula used has been cross-validated against more accurate 'gold standard' such as DXA.

One important limitation of the study is that the population group could not be randomly selected. Under-representation of obese subjects is very likely, but this is not necessarily a shortcoming for establishing reference values for healthy individuals. We believe that despite the large number of individuals studied, the group is not necessarily representative of the whole helvetical population.

FFM *vs* FM indexes: usefulness in obesity and leanness

One advantage of FMI, as compared to the BMI concept, is that it amplifies the relative effect of aging on body fat. Expression of a change in body fat mass in absolute value fails to allow an appropriate comparison among subjects of different sizes.

We believe that the definition of obesity based on relative body fat (ie percentage) remains of great value for the definition of obesity. However, in a situation in which a patient is losing weight without substantially changing his/her relative body fat (as is the case with crash diets), the calculation of FMI will quantitatively reveal the amount of body fat store lost.

For example, if a patient of 100 kg loses 10 kg (ie 10% of her body weight) with the same proportion of body fat as contained initially in her body (say 50%) she will also drop

her FMI (and FFMI) by 10%, despite no change in relative body fat. It is true that the relative drop will be identical to the loss of body fat expressed in absolute value (10%). However, the FMI value obtained will allow a more appropriate comparison of the decrease in fatness with other patients of different heights who have lost the same amount of weight but have a different initial BMI.

We could take an opposite example during a slimming program, where BMI may fail to change substantially because of an associated physical activity program (strength training), but body fat mass may substantially decrease and hence FMI as well.

The high sensitivity of FMI (respectively FFMI) to a slight change of body fat stores (respectively lean tissue mass), compared to the use of BMI or percentage body fat as factors, make it an index of potential interest for assessing static and dynamic nutritional status and energy reserves endpoints.

FMI and FFMI cut-off points

In order to conform to the classical BMI cut-off points set out by WHO specification, we have taken a BMI of 18.5, 20 and 25 kg/m^2 and we have determined what is the corresponding values for FFMIs and FMIs using regression analysis of BMI *vs* FFMI, respectively *vs* FMI. Table 3 gives these results. It is apparent that, the P25 and P75 for FFMI and FMI distribution correspond well to the cut-off of BMI's of 20 and 25 kg/m^2 respectively. This is particular true in women: at a BMI of 20 kg/m^2 the corresponding FFMI is 15.1 kg/m^2, and P25 is equal to 15.0. Similarly, at a BMI of 25 kg/m^2, the corresponding value of FFMI is 16.7 kg/m^2, and P75 is equal to 16.6.

When the BMI increases with age, it is expected that an increase fat storage would specifically affect FMI and very little FFMI. The impact of the weight gain in the percentile distribution cannot be assessed without carrying out a prospective study. The fact that we used a standardized BMI range at all ages is evidence that the rise in BMI with age is not characteristic of all populations and is not something desirable.

Van Itallie *et al*[21] reported a FMI of 2.4 kg/m^2 at percentile 5 in male subjects compared to a calculated value of 2.5 kg/m^2 for a BMI of 20 kg/m^2 in the present study (Table 3), corresponding to about half of the median value of the present study. Friedl *at al*[42] found a critical fat mass in absolute value of 2.5 kg (corresponding to a FMI of 0.8 kg/m^2) at a minimum level of body fat of 4–6% in young men involved in army combat subjected to strenuous exercise combined with borderline energetic diet. In the Minnesota cohort[21] the mean FMI in the men was found to be 0.9 kg/m^2 following 24 weeks of semi-starvation.

Taken together, these results show that a FMI of approximately 1 kg/m^2 can be considered as a 'critically low' value in both men and women, since it is below P5 (Table 2).

Sarcopenic obesity has been defined as a low FFM associated with a high body fat. Baumgartner *et al*[43] defined sarcopenic obesity, associated with greater disability in elderly subjects, as a relative FFM lower than 73% (ie a relative body fat greater than 27%) in men and a FFM lower than 62% (ie a body fat greater than 38%) in women. Sarcopenic obesity could well be defined on the basis of FFMI and FMI, ie a low FFMI associated with high FMI, but the diagnosis of sarcopenic obesity based on these two indexes remains to be further defined.

The concept of FFMI could also be useful for calculating the relative muscle hypertrophy in body builders and other sports where heavy muscular body build needs to be measured quantitatively in order to exclude false diagnosis of excess body fat based on single BMI measurements. In fact, different combinations between low (below P5) and high (greater than P95) FFMI, respectively high *vs* low FMI, could be considered in practice. Four typical situations may be envisaged: (1) low FFMI *vs* high FMI judged as sarcopenic obesity; (2) low FFMI *vs* low FMI corresponding to chronic energy deficiency; (3) high FFMI *vs* low FMI as evidence of muscle hypertrophy; and (4) high FFMI *vs* high FMI, which suggests combined excess FFM and FM (such as in a *SUMO* somatotype). Note that in our sample, the 95th percentile of FFMI was 21.1 in male and 17.6 kg/m^2 in female. For the FMI the values were 7.0 in male and 8.7 kg/m^2 in female. Since the sum of FFM + FM index is mathematically equivalent to BMI, the addition of the two will generate a BMI value of 28.1 in males and 26.3 kg/m^2 in females. In other words, this means that if a subject is at percentile 95 for both FFMI and FMI, the BMI will be still below 30 kg/m^2, the WHO criteria for obesity based on BMI.

What cut-off point is obtained with 'normal' or excessive BMI reference ranges?

If one takes as normal BMI range values of 18.5–25 kg/m^2, then corresponding values for FMI and FFMI can be defined on the basis of body composition reference ranges. If the reference range for relative body fat in (young) women is taken as rounded off values bracketing 20–30% (for memotechnic reasons), then one could calculate a theoretical reference range for FMI in women of $18.5 \times 0.2 = 3.7$ kg/m^2 and $25 \times 0.3 = 7.5$ kg/m^2. This is close to the values defined in the present study at P5 (3.5 kg/m^2) and at P95 (8.7 kg/m^2) in young women. Interestingly, these values also correspond to the classical cut-off points of BMIs of 18.5 and 25 kg/m^2 (ie 3.9 and 8.3 kg/m^2 in women, see Table 3). Similar calculations can be made in men to define expected ranges of 'normality' of FMI, but full consistency among different approaches may not be the rule.

It is interesting to note that BMI misclassified a significant proportion of subjects with high FMI but 'normal' BMI. Indeed, one quarter of subjects with a BMI in the 25–29.9 kg/m^2 category fell in the normal range based on relative body fat or FMI.

FMIs greater than 8.2 kg/m^2 in men and 11.8 kg/m^2 in women would define the 'overfat' status (rather than the

overweight range) in terms of fat mass. In addition, since a fraction of subjects falling in the 'normal' BMI category may have an elevated FMI, this suggests that this category of patients should normalize their body fat irrespective of the BMI value. This is particularly important in subjects having an android fat distribution since this confers substantial additional risk factors.

Deurenberg-Yap *et al*[44] have recently demonstrated that there is a discrepancy between average BMI and average relative body fat in certain ethnic group (Chinese population). Their study showed a higher percentage body fat for the same BMI as compared to Caucasians. This indicates that that FMI will be higher at the same BMI compared to other populations. This also means that population-specific BMIs need to be developed when body composition is unknown, whereas population-specific FMI may be less warranted.

In summary, reference intervals of FMI *vs* FFMI can be used as indicative values for the evaluation of nutritional status (overnutrition and undernutrition) of apparently healthy subjects and can provide complementary information to the classical expression of body composition reference values.[45] FMI is able to identify individuals with elevated BMI but without excess FM. Conversely, FMI can identify subjects with 'normal' BMI but who are at potential risk because of elevated FM.

Future investigations that include body composition measurements will help to elucidate the relationship between the magnitude of FMI (respectively FFMI), potential risk factors and subsequent mortality. The present study assessed the degree of variability of FFMI and FMI in apparently healthy subjects but it definitely warrants complementary investigations in large groups of subjects of various ethnic origin. This report is a preliminary attempt to analyze a large set of data and to promote future research in the body composition area. Furthermore the concept of FMI and FFMI could be also developed for pediatric subjects, although less information on body composition is available in certain age categories (young children).

The relationships of high fat mass (respectively high FMI) needs to be further explored on the basis of longitudinal studies in order to determine what range of FMI results in the lowest disability, low risk factors and prolonged longevity.

Acknowledgements

We thank the Foundation *Nutrition 2000 Plus* for its financial support. We are indebted to the dietitians at the Geneva University Hospital for their help.

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