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Original Communication
The validity of predicted body fat percentage from body mass index and from impedance in samples of five European populations

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Objectives: To test and compare the validity of a body mass index (BMI)-based prediction equation and an impedance-based prediction equation for body fat percentage among various European population groups.
Design: Cross-sectional observational study.
Settings: The study was performed in five different European centres: Maastricht and Wageningen (The Netherlands), Milan and Rome (Italy) and Tampere (Finland), where body composition studies are routinely performed.
Subjects: A total of 234 females and 182 males, aged 18–70 y, BMI 17.0–41.9 kg/m^2.
Methods: The reference method for body fat percentage (BF%$_{REF}$) was either dual-energy X-ray absorptiometry (DXA) or densitometry (underwater weighing). Body fat percentage (BF%) was also predicted from BMI, age and sex (BF%$_{BMI}$) or with a hand-held impedance analyser that uses in addition to arm impedance weight, height, age and sex as predictors (BF%$_{IMP}$).
Results: The overall mean ($\pm$s.e.) bias (measured minus predicted) for BF%$_{BMI}$ was 0.2 ± 0.3 (NS) and -0.7 ± 0.3 (NS) in females and males, respectively. The bias of BF%$_{IMP}$ was 0.2 ± 0.2 (NS) and 1.0 ± 0.4 ($P<0.01$) for females and males, respectively. There were significant differences in biases among the centres. The biases were correlated with level of BF% and with age. After correction for differences in age and BF% between the centres the bias of BF%$_{BMI}$ was not significantly different from zero in each centre and was not different among the centres anymore. The bias of BF%$_{IMP}$ decreased after correction and was significant from zero and significant from the other centres only in males from Tampere. Generally, individual biases can be high, leading to a considerably misclassification of obesity. The individual misclassification was generally higher with the BMI-based prediction.
Conclusions: The prediction formulas give generally good estimates of BF% on a group level in the five population samples, except for the males from Tampere. More comparative studies should be conducted to get better insight in the generalisation of prediction methods and formulas. Individual results and classifications have to be interpreted with caution.
Descriptors: body composition; body fat percentage; body mass index; bioelectrical impedance; international comparison; validation
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Introduction

The WHO (WHO, 1995, 1998) defines overweight and obesity at body mass index (BMI) cut-off points of 25 and 30 kg/m^2, respectively, as from these BMI values onwards morbidity and mortality starts to increase in (Caucasian) populations. There is increasing evidence that these cut-off values are not valid for all populations (Wang *et al*, 1994; Swinburn *et al*, 1996; Luke *et al*, 1997; Deurenberg *et al*,

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1998; Deurenberg-Yap *et al*, 2000) as the relationship between BMI and percentage body fat (BF%) differs among (ethnic) population groups and it is the amount of body fat, rather than the amount of excess weight that determines the health risks of obesity (WHO, 1998; Deurenberg *et al*, 1998). This explains the increasing interest of scientists and general public in body fat measurements. Body composition methods suitable for epidemiological studies as well as for personal use should be both reliable and easy to perform. Three methods are in principle suitable for epidemiological measurements. From BMI BF% can be predicted, using age- and sex-specific prediction equations (Durnin & Womersley, 1974; Deurenberg *et al* 1991; Gallagher *et al*, 1996; Deurenberg-Yap *et al*, 2000). The prediction formulas are, however, ethnic-specific (Deurenberg *et al*, 1998). Skinfold thickness measurements provide good estimates of body fat (Durnin & Womersley, 1974), but the observer needs to be skilled, a prerequisite that is less important for bioelectrical impedance measurements (Lukaski *et al*, 1985; Jebb & Elia, 1993). In bioelectrical impedance measurements the conductance of a small alternating current through the body is measured (NIH, 1994). As the conductance is mainly determined by the amount of water, which is only present in the fat-free mass, impedance measurements allow assessment of the fat-free mass and, by difference with body weight, of BF% (NIH, 1994). The classical (total body) bioelectrical impedance method measures impedance from foot to hand (Lukaski *et al*, 1985). The subject needs to lay supine, which limits the practical application of the method, especially in field situations.

It was shown in earlier studies (Baumgartner *et al*, 1989; Fuller & Elia, 1989) that segmental impedance measurements (measuring only segments of the body as the legs or the arms) also allow fairly accurate assessments of body composition. Based on those observations, impedance analysers were developed that measure only segmental impedance. Instruments are available commercially which measure impedance of the legs (from foot to foot) simultaneously with body weight while the subject stands on a weighing scale (Nunez *et al*, 1997; Jebb *et al*, 2000). Other instruments measure impedance of the arms (from hand to hand) and use built-in software to assess BF% (Loy *et al*, 1998), using weight, height, age and sex as additional parameters. Those segmental impedance instruments are easy to use and have the advantage that they are relatively inexpensive as they are mass-produced.

Generally, prediction formulas for body composition tend to be population-specific. One possible reason is cross-population differences in parameters that are used in the equation (Deurenberg, 1992; Norgan, 1995). Theoretically, impedance-based predictions, using impedance, weight, height, age and sex as predictors, should result in more accurate assessments of body fat than BMI-based formulas. This is because impedance should, at least partially, distinguish between fat and fat-free mass.

The aim of the present study was to test and to compare the validity of predicted body fat from an anthropometric equation and predicted body fat from a bioelectrical impedance-based prediction equation. The predictors for the anthropometric equations were BMI, age and sex and for the impedance based equation (arm) impedance, weight, height, age and sex. The study was performed in five European centres that regularly perform body composition studies. A standardised protocol was followed.

Subjects and methods

The study was performed in five European centres: Department of Human Biology, University of Maastricht, The Netherlands; the International Centre for the Assessment of Body Composition, Department of Food Science and Microbiology, University of Milan, Italy; Department of Human Physiology, University 'Tor Vergata', Rome, Italy; UKK Institute for Health Promotion Research, Tampere, Finland; and Department of Nutrition and Epidemiology, Wageningen University, The Netherlands. The centres are indicated throughout this paper as Maastricht, Milan, Rome, Tampere and Wageningen. Approval for the study was obtained from the Medical Ethical Committees in each centre.

The subjects participated in ongoing body composition studies. In addition to the standard measurements, body composition was also assessed using an Omron Body Fat Monitor, model BF306. Because of the nature of the study the subjects are not comparable in age and body fatness among the centres. Some characteristics of the subjects are given in Table 1. All measurements were done at least 3 h after a meal (including drink), and subjects were requested to refrain from strenuous exercise 12 h prior to the measurements. Subjects were asked to empty their bladder before the measurements. Females were not measured during their menstrual period.

Body weight was measured in underwear or swimsuit to the nearest 0.1 kg. Body height, accurate to 0.5 cm, was measured without shoes with the Frankfurt plane horizontal. BMI was calculated as weight/height^2 (kg/m^2). From BMI body fat percentage was predicted ($BF\%_{BMI}$) using an age- and sex- specific prediction equation (Deurenberg *et al*, 1991).

Body fat was estimated using a hand-held impedance analyser ($BF\%_{IMP}$), following the instructions given in the manufacturer's manual (Omron BF306, Omron Healthcare Europe BV, Hoofddorp, The Netherlands). During the measurement the instrument recorded impedance from hand to hand and consequently calculated body fat percentage from the impedance value and the pre-entered personal particulars (weight, height, age and sex). The incorporated formula is not known. Predicted BF% using the BF306 is higher compared to an earlier version (BF300) of this type of body fat analyser, especially in females (unpublished observations).

In addition, BF% was measured with the reference technique normally used in each centre ($BF\%_{REF}$). For Milan and Rome this is dual-energy X-ray absorptiometry

Table 1 Characteristics of the female and male subjects in each study site (mean ± s.d.)

		Age (y)		*Weight (kg)*		*Height (cm)*		*BMI (kg/m²)*		*BF%REF (%)*	
		mean	*s.d.*	*mean*	*s.d.*	*mean*	*s.d.*	*mean*	*s.d.*	*mean*	*s.d.*
Maastricht	Female (59)	35.3	15.6	65.4	10.8	168.0	7.6	23.2	3.9	30.0	8.4
	Male (39)	40.4	17.5	77.5	10.0	178.9	6.6	24.3	3.4	20.5	8.4
Milan	Female (25)	41.2	13.9	62.3	7.6	164.6	6.4	23.0	3.1	31.7	7.2
	Male (25)	36.7	10.8	69.5	7.6	174.0	6.3	23.0	2.2	19.6	7.1
Rome	Female (26)	46.2	13.0	70.0	13.9	161.0	5.7	27.1	5.9	39.7	8.9
	Male (18)	34.6	11.7	87.1	12.1	178.8	6.6	27.2	2.8	23.2	8.8
Tampere	Female (62)	39.1	13.2	61.5	8.5	165.2	6.3	22.5	2.6	29.1	5.3
	Male (50)	40.3	12.4	77.1	9.3	178.0	6.0	24.3	2.7	22.9	5.9
Wageningen	Female (62)	27.1	10.2	65.1	9.0	168.7	7.7	23.0	3.8	30.5	6.7
	Male (50)	27.1	10.6	78.2	8.4	185.1	6.9	22.8	2.4	16.2	6.6
Total	Female (234)	36.0	14.5	64.5	10.1	166.3	7.4	23.4	4.0	31.2	7.8
	Male (182)	35.6	14.0	77.4	10.1	179.7	7.4	24.0	3.0	20.1	7.6

BMI, body mass index; $BF\%_{REF}$, body fat percentage from reference method.

(DXA) using a Lunar DPXL whole body X-ray densitometer (Lunar Radiation Corp., Madison, WI; software version 1.35, fast scan mode). In Maastricht, Tampere and Wageningen the reference method is densitometry by underwater weighing (Going, 1996). Residual lung volume was measured using helium dilution (Motley, 1957). A correction of 100 ml was made for intra-intestinal gas volume (Going, 1996). In Maastricht and Wageningen lung volume was measured simultaneously with the underwater weighing and the subject in a supine position. In Tampere lung volume was measured before the underwater weighing with the subject sitting in the water tank submerged to the neck. Underwater weight was also measured in the sitting position but completely submerged. These two different approaches do not differ markedly (Going, 1996). A detailed description for the technique in each centre is published elsewhere (Jansen *et al*, 1992; Fogelholm *et al*, 1996; Schrauwen *et al*, 1997). From body density, body fat was calculated using Siri's formula (Siri, 1961).

Although there might be differences between the two 'reference' methods used (DXA and densitometry), it is assumed that the two methods give comparable results. This is justified by the fact that in the 112 Wageningen subjects (which were measured by both techniques) $BF\%_{DXA}$ and $BF\%_{DENS}$ differed by only 0.5 ± 3.1% ($P = 0.30$) with the slightly higher value for underwater weighing.

Statistical analyses were performed using SPSS for Windows version 10.0.0 (SPSS, 1999). The validity of predicted BF% was tested using a variety of tests. The bias (reference method minus predicted value) of predicted BF% was tested against zero (*t*-test) and tested for differences between the different study sites using ANOVA with Bonferroni tests for multiple comparisons. The dependency of the bias on BF% and age was tested using (partial) correlation analysis and consequently analysis of covariance (ANCOVA) was used to correct for the effect of these factors on the bias. Where data were combined, sex was coded as dummy variable and taken into account. Bland and Altman plots (1986) were used to test agreement between methods. Results are expressed as mean ± standard deviations (s.d.) unless otherwise stated. A *P*-value < 0.05 was regarded as significant. All tests were two-sided.

Results

In total 416 subjects participated in the study. The 234 females ranged in age from 19 to 70 y, in BMI from 17.0 to 41.9 kg/m² and in BF% from 13.8 to 57.1%. The 182 males ranged in age from 18 to 70 y, in BMI from 17.3 to 34.9 kg/m² and in BF% from 5.3 to 36.4%. The characteristics of the subjects in the various centres are given in Table 1. In both males and females there are significant differences among the centres in age, weight, height and BMI, with Wageningen having the younger and taller subjects and Rome having the subjects with the highest weight, BMI and BF%.

For the overall female population $BF\%_{BMI}$ (31.0 ± 6.7) and $BF\%_{IMP}$ (31.0 ± 6.1) were not significantly different from $BF\%_{REF}$ (31.2 ± 7.7). For the overall male population $BF\%_{BMI}$ (20.8 ± 5.6) was not significantly different from $BF\%_{REF}$ (20.1 ± 7.6) but $BF\%_{IMP}$ (19.1 ± 6.3) was slightly but significantly ($P < 0.01$) lower than $BF\%_{REF}$. The correlation coefficients between $BF\%_{REF}$ and $BF\%_{IMP}$ for both females and males were higher than the correlation between $BF\%_{REF}$ and $BF\%_{BMI}$ (0.87 and 0.83 *vs* 0.78 and 0.78 in females and males, respectively). For the total population (males and females combined) the standard error of estimate (s.e.e.) of the regression between $BF\%_{REF}$ and $BF\%_{BMI}$ was 4.8% ($r^2 = 0.74$). The s.e.e. of the regression between $BF\%_{REF}$ and $BF\%_{IMP}$ was 4.1% and the r^2 was 0.81.

The biases (measured minus predicted BF%) of both prediction methods were correlated with level of body fatness and age. For all males and females combined, the BMI-based formula had a bias (mean ± s.e.) of

−0.2 ± 0.2%. In subjects younger than 35 y the bias was + 0.2 ± 0.3% and in subjects older than 35 y the bias was − 0.7 ± 0.3%. The overall bias of the BIA based formula was + 0.6 ± 0.2%. In subjects younger than 35-y-old this bias was − 0.5 ± 0.2% and for subjects older than 35 y this bias was + 1.8 ± 0.3%. The age effects differed remarkable among the centres and were dependent on the level of body fatness (results not shown). Table 2 gives the Pearson's correlation coefficients between the biases and age and biases and level of body fatness and also the partial correlation coefficients after controlling for either age or level of BF%. The correlation of the bias with age disappeared after correction for body fatness in both males and females for $BF\%_{IMP}$, showing that the correlation with age was nested with BF%. The relationship of the bias with level of body fatness is also shown in Figure 1.

ANOVA revealed that there were differences in biases for the two prediction methods among the centres. For females, the bias of $BF\%_{BMI}$ was different between Rome and Tampere, between Wageningen and Maastricht and between Wageningen and Tampere. The bias of $BF\%_{IMP}$ was different between Rome *vs* the other study sites. For males, the bias of $BF\%_{BMI}$ was not different among the study sites. The bias of $BF\%_{IMP}$ was different only between Tampere and the other sites.

The differences in bias of $BF\%_{BMI}$ among the centres disappeared after correction for differences in age and BF% among the centres. For the bias of $BF\%_{IMP}$ in the males, only Tampere remained significantly different from the other centres after correction for age and level of body fatness.

Table 2 Pearson correlation coefficient and partial correlation coefficients of bias with level of body fat percentage and age[a]

	BF%	*Age*	*BF%*	*Age*
	Correction for			
	—	—	*Age*	*BF%*
Bias of $BF\%_{BMI}$				
females	0.52	−0.29	0.76	−0.69
males	0.67	0.01(NS)	0.83	−0.66
Bias of $BF\%_{IMP}$				
females	0.64	0.24	0.61	0.06 (NS)
males	0.55	0.28	0.49	0.07 (NS)

[a]All values significant unless otherwise stated.
Bias, measured minus predicted body fat percentage; $BF\%_{BMI}$, body fat percentage predicted from body mass index; $BF\%_{IMP}$, body fat percentage predicted from impedance.

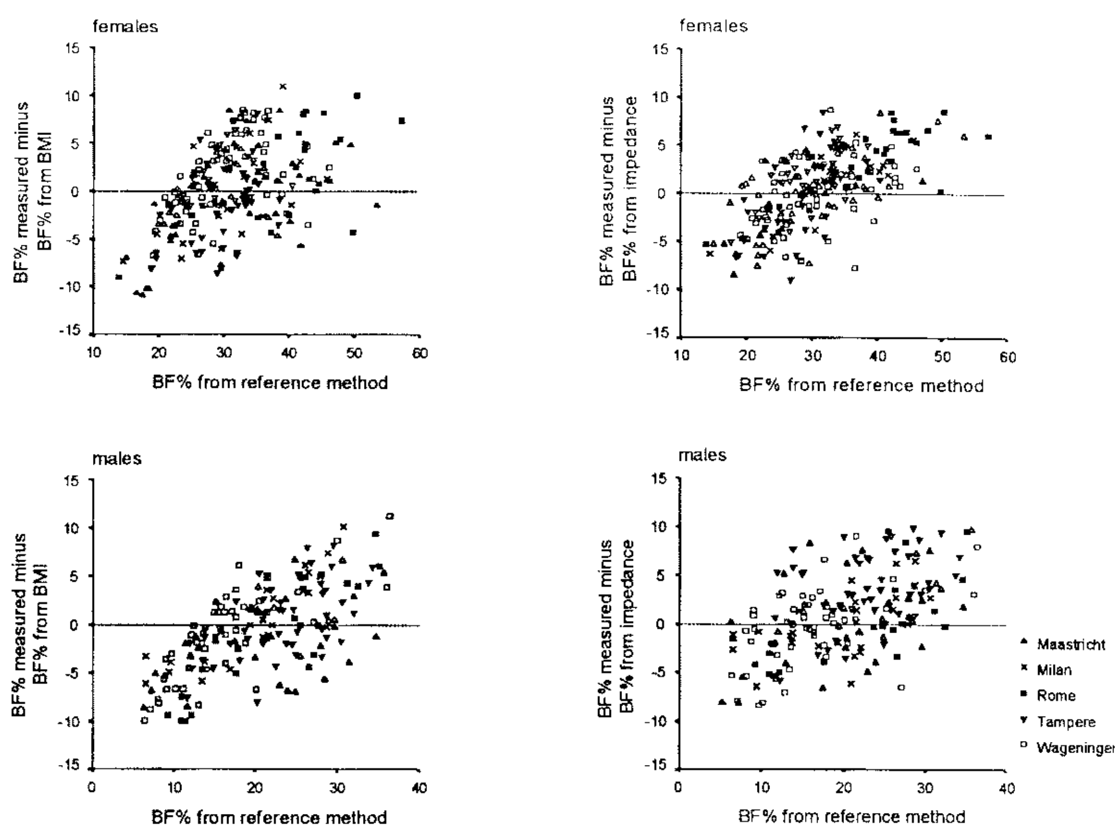

Figure 1 Bias of predicted body fat percent from body mass index and from impedance in males and females in five European centres.

The bias of $BF\%_{BMI}$ was significant different from zero in the females from Tampere, the males from Maastricht and the females and males from Wageningen (see Table 3). The bias of $BF\%_{IMP}$ was significantly different from zero for the females from Rome and the males from Finland only. After correction for differences in level of body fatness and age the bias of $BF\%_{BMI}$ was in none of the study sites different from zero anymore. The bias for $BF\%_{IMP}$ in the Rome females disappeared after correction for level of body fatness but the bias for the Tampere females became borderline significant ($P = 0.04$). The bias in the males from Tampere remained significant after correction for age and BF%. The corrected and uncorrected data of the biases are given in Table 3.

The correlation between the biases of $BF\%_{BMI}$ and $BF\%_{IMP}$ was 0.580 ($P < 0.001$) for females and 0.609 for males ($P < 0.001$). The bias of $BF\%_{BMI}$ was in 89% of the females and in 89% of the males between −8 and +8 percentage points BF%. The bias for $BF\%_{IMP}$ was in 96% of the females and in 91% of the males between the −8 and +8 percentage points BF%.

If obesity were defined as BF% greater than 25% in males and greater than 35% in females, 7% of the females and 8% of the males would be falsely classified as obese with the BMI-based formula. These figures are 4 and 5% for the impedance-based formula. In females 32 and 24% of the obesity classification would be false negative for the BMI and impedance-based formulas, respectively. In males these figures are 41 and 44%. Nearly half of the misclassified obese males (for BMI and impedance based formula) were from Tampere.

Discussion

The subjects in each study centre participated in ongoing studies on body composition and/or energy metabolism. Although an attempt was made to have a wide age distribution and a wide distribution in BMI (as apparent fatness), the participants differ in age and BMI among the study centres. As prediction equations tend to depend on level of body fatness and sometimes also on age, corrections were made for these variables whenever necessary. For a validation study representativeness for the total population is not a prerequisite and a wide range in age and BMI is more important.

In three study centres densitometry (underwater weighing) was used as method of reference and in two centres DXA. In Maastricht and Wageningen the underwater weighing follows the same procedure and in an earlier study (Deurenberg *et al*, 1994) it was shown that results between these two laboratories are comparable. The underwater procedure in Tampere differs slightly (measurement position, measurement of lung volume) but it is generally accepted that these procedures do not lead to substantial differences in results (Wilmore, 1969; Going, 1996). The comparability of the DXA measurements in Milan and Rome with the densitometric measurements of body fat in Maastricht, Tampere and Wageningen is of more concern. However, in Milan and in Rome the same Lunar DPXL system is used as is also available in Wageningen, and the subjects in Wageningen were measured by DXA as well as by densitometry. In the 112 subjects in Wageningen $BF\%_{DXA}$ was 23.6 ± 9.8 and $BF\%_{DENS}$ was 24.1 ± 9.7. The difference of 0.5 ± 3.1% was not significant

Table 3 Bias of predicted body fat percent from body mass index and from impedance before and after correction for age and BF% (mean ± s.e.)

		$BF\%_{REF}$ minus				*$BF\%_{REF}$ minus*			
		$BF\%_{BMI}$		*$BF\%_{IMP}$*		*$BF\%_{BMI}$*		*$BF\%_{IMP}$*	
		Before correction				*After correction for age and BF%*			
		mean	*s.e.*	*mean*	*s.e.*	*mean*	*s.e.*	*mean*	*s.e.*
Maastricht	Female (59)	−0.6	0.6	−0.5	0.5	−0.1	0.4	−0.2	0.4
	Male (39)	−1.7*	0.8	0.5	0.7	−0.9	0.4	0.5	0.6
Milan	Female (25)	0.0	0.9	0.3	0.7	0.9	0.6	0.3	0.6
	Male (25)	−0.2	0.9	0.0	0.7	0.4	0.5	0.1	0.7
Rome	Female (26)	1.9	1.0	3.6*	0.7	−0.3	0.6	1.1	0.6
	Male (18)	−1.2	1.5	0.4	1.2	0.5	0.6	−0.6	0.8
Tampere	Female (62)	−1.5*	0.6	0.1	0.5	0.3	0.4	0.9*	0.4
	Male (50)	0.6	0.5	3.5*	0.5	−0.3	0.4	2.8*	0.5
Wageningen	Female (62)	2.1*	0.6	−0.5	0.4	0.5	0.4	−0.6	0.4
	Male (50)	−1.3*	0.7	−0.5	0.6	0.5	0.4	0.5	0.5
Total	Female (234)	0.2	0.3	0.2	0.2	0.5	0.3	0.3	0.2
	Male (182)	−0.7	0.3	1.0*	0.4	−0.7	0.4	0.6	0.3

Bias, measured minus predicted body fat percentage; $BF\%_{REF}$, body fat percentage from reference method; $BF\%_{BMI}$, body fat percentage from body mass index; $BF\%_{IMP}$, body fat percentage from impedance.
*$P < 0.05$ from zero.

($P = 0.30$). Although this finding is not a guarantee that the instruments in Milan and Rome give comparable results (Paton *et al*, 1995), it is assumed that the reference methods are comparable throughout the total sample. This methodological problem is inherent to international comparative studies in which it is nearly impossible to measure subjects in the same centre. The ideal situation would be a portable reference method, for example deuterium oxide dilution (Werkman *et al*, 2000).

The prediction of BF% from BMI, age and sex assumes that, when the BMI increases over a certain threshold, the excess value is for a fixed part due to body fat. This assumption certainly has its flaws as is also apparent from the correlation of BMI with the fat-free mass (for example in this population $r = 0.25$ ($P < 0.001$) in females and 0.29 ($P < 0.001$) in males). It explains why the prediction formula generally underestimates BF% at higher values of body fat (see Figure 1). Also, factors like body build and relative leg length affect the BMI as predictor for body fatness (Deurenberg *et al*, 1999; Snijder *et al*, 1999). Overall the prediction of BF% from BMI is good on a population level with a mean bias of +0.2 BF% in females and −0.7 BF% percent in males (Table 3). The bias was correlated with age and level of body fatness and these correlations were independent of each other, as shown by partial correlation analyses (Table 2). Generally the BMI-based formula tends to underestimate BF% in younger subjects and overestimate it in older subjects. The impedance-based formula tends to do the opposite, but the underestimation at older age is mainly due to the higher body fat content at older age. Differences in bias of $BF\%_{BMI}$ among the centres disappeared completely after correction for level of body fatness and age and the bias was in none of the centres nor in the total population different from zero (Table 3). These results support the validity (at population level) of the used BMI-formula in European Caucasian populations (Deurenberg *et al*, 1998).

The prediction of BF% using arm impedance, weight, height, age and sex assumes that measured arm impedance (hence water content in the arm) is representative for the total body. It is obvious that this is not necessarily true. In subjects with relatively more arm muscle, the total amount of fat-free mass will be overestimated with this technique and hence BF% will be underestimated. Also, in subjects with relatively long arms, the measured impedance will be high and hence fat-free mass low and thus calculated BF% high (Snijder *et al*, 1999). There are reported differences in relative arm length among populations and it is known that within population groups the variability in arm length is high (Eveleth & Tanner, 1976). Recently we showed that small differences in predicted BF% using hand-held impedance among ethnic groups could be (partly) explained by relative (to body height) arm length (Deurenberg & Deurenberg-Yap, 2001). In the total female population the bias of predicted $BF\%_{IMP}$ was small and not significantly different from zero. In the total male group it was slightly significantly different from zero (Table 3). In the subgroups the bias was exceptionally large in the Rome females and in the Tampere males. Correction for the effect of body fatness lowered the overall bias in males and females to insignificant values. The bias in the Rome females decreased remarkably from 3.6 to 1.1 percentage point and was not significantly different from zero anymore. However, in the Tampere males the bias decreased only slightly from 3.5 to 2.8 percentage point and remained significantly different from zero. The bias in the Tampere males was also significantly different from the other centres. Reasons for this exceptionally large bias remain obscure. The Tampere males were not exceptionally tall or heavy (factors that could have influenced the bias), and their relatively high BF% (Table 1) is controlled for in the analyses. It could be that they are relatively muscular in the arms or that their arm length is relatively short, but no information on this is available. Although an error in the method of reference as source of the bias cannot be excluded, there is no reason to assume this, as the underestimation is obvious for the whole group of Tampere males but is not clearly apparent in the Tampere females. Although the prediction of BF% on a group level was good (with the exception of the Tampere males), the individual predictions were less satisfactory (see also Figure 1). If an error of 4 percentage points BF% is considered as reasonable (Lohman, 1992), which is in line with the standard error of estimate of most prediction equations (Durnin & Womersley, 1974; Deurenberg *et al*, 1991; Gallagher *et al*, 1996), an individual error of up to 8% should be acceptable. In 11% of the subjects the bias of $BF\%_{BMI}$ was larger, whereas this figure was only 4% for the impedance-based prediction. This is to be expected as the impedance formula uses additional information, which, theoretically, enables to distinguish between fat and fat-free mass. If the two approaches were used to classify obesity (here defined as $BF\% \geq 25\%$ in males and $BF\% \geq 35\%$ in females), independent of age (WHO, 1995, Deurenberg *et al*, 1998), the misclassification would be considerable for both methods. The false negative classification for obesity is high with 32% of the obese females and 41% of the obese males being false negative with the BMI-based formula and 24% for the obese females and 44% for the obese males with the impedance-based formula. This high misclassification of obesity is in line with the positive correlation of the bias with level of body fatness (Table 2 and Figure 1) and shows clearly that individual predictions have to be cautiously interpreted. As this misclassification is mainly in the Tampere males, it may be possible that body build factors that have an impact on the prediction might be at least partly responsible for the bias.

Summary

The prediction of BF% using BMI or impedance based formulas showed small bias between the study centres, bias that could be partly explained by differences in age and/or

level in BF%. Although the prediction was generally good at a population level, individual biases were sometimes high, especially in the BMI-based formula.

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