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Validity of body composition methods across ethnic population groups

Abstract Most in vivo body composition methods rely on assumptions that may vary among different population groups as well as within the same population group. The assumptions are based on in vitro body composition (carcass) analyses. The majority of body composition studies were performed on Caucasians and much of the information on validity methods and assumptions were available only for this ethnic group. It is assumed that these assumptions are also valid for other ethnic groups. However, if apparent differences across ethnic groups in body composition 'constants' and body composition 'rules' are not taken into account, biased information on body composition will be the result. This in turn may lead to misclassification of obesity or underweight at an individual as well as a population level. There is a need for more cross-ethnic population studies on body composition. Those studies should be carried out carefully, with adequate methodology and standardization for the obtained information to be valuable.

Key words Body composition • Validity • Ethnicity

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Introduction

Body composition can be measured at different levels, ranging from atomic, molecular, cellular, tissue, to whole body levels [1]. Information obtained at one level can be transformed into other levels, using, for example, chemical constants (as for the calculation of body protein from body nitrogen) or using experimentally or statistically derived constants or relationships. Body composition methods can be divided into direct, indirect, and doubly indirect methods [2]. Direct methods measure directly the component of interest, and examples are chemical carcass analysis or in vivo neutron activation analysis. Indirect methods use constants and rules based on direct methods. For example, densitometry assumes a constant density for fat-free mass (FFM) of 1.100 kg/l, which is based on the chemical composition of fat-free mass as obtained from carcass analyses. Doubly indirect methods are based mainly on a statistical relationship between easily measurable body parameters and a body composition component as measured by an indirect method. An example is the prediction of body fat percent (BF%) from skinfold thickness. Most fundamental body composition studies have been conducted in Europe and the USA, thus most rules and assumptions are based on data obtained from Caucasians. Assumptions and developed prediction equations have been applied to other ethnic groups, a priori assuming their validity. In recent years, much information has become available that seriously question the general validity of many common assumptions and prediction formulas in all ethnic groups.

This paper gives some examples of methods that require ethnic-specific assumptions and prediction formulas.

Validity of constant density and hydration of fat-free mass across ethnic groups

Data on carcass analyses showed that the density of the FFM is 1.10 kg/l and the density of the fat mass (FM) is 0.90 kg/l. Thus, body density measurements, for example by underwater weighing or by air displacement, allow the calculation of body fat content. The use of chemical multi-compartment models [3] enables the independent assessment of the various components of FFM (i.e., minerals, protein, and water). The composition and density of FFM varies slightly with age and sex, and several studies have shown significant differences in composition and density among ethnic groups. As an example, Table 1 gives the composition and calculated density of FFM of age-matched females of different ethnic background [4]. Failing to adapt the calculation formula for BF% to account for differences in FFM density may result in systematic biases of up to 3% in estimates.

The hydration of FFM is relatively constant at about 73%, but is slightly age- and perhaps also body fatness-dependent (the latter in cases of extreme obesity) [5, 6]. The amount of body water can be determined by dilution techniques, for example using deuterium oxide [2, 5]. If a constant hydration of FFM is assumed, the latter can be calculated. Body fat is then calculated as the difference between weight and FFM.

In most comparative studies, no differences are reported in hydration of FFM between black and white Americans [7]. Wang et al. reported a lower hydration of FFM in Asians [8], but in another study they question the accuracy of density measurements (that are needed in the calculations) in Asians [9]. Recently we studied the hydration of FFM of Dutch Caucasians and Singapore Chinese, Malays and Indians [10, 11]. Although some statistically significant differences were found, it was concluded that these differences are too small to be biologically relevant.

The cross-ethnic validity of densitometry and hydrometry is extremely important, since they are often used as reference methods for predictive methods. A bias in the reference method will automatically result in biased predicted values.

Validity of predictive methods across ethnic groups

The skinfold methodology assumes that (within age and gender groups): (1) the thickness of the subcutaneous fat layer is representative of the total amount of body fat; (2) the sites where the skinfolds are measured are representative of the total subcutaneous fat layer; and (3) there are no differences in subcutaneous fat patterning.

From a comparative study in black and white Americans [12], it can be concluded that generalized skinfold prediction equations have different validity among ethnic groups. Of note is the different subcutaneous fat distribution (i.e., fat patterning) between blacks and whites, blacks having generally less subcutaneous fat in the extremities and more subcutaneous fat in the trunk. This is obvious, for example, from the (subscapular+suprailiac)/(biceps+triceps) skinfold ratio [12, 13]. Norgan [14] concluded that differences in subcutaneous fat patterning could be a reason for the different validity of various prediction equations across ethnic groups. Also in a comparative study among Singaporean Chinese, Malays, and Indians, we found differences in subcutaneous fat distribution. In addition, the age-related increase in body fatness was much lower in Singaporeans than in Caucasians (unpublished data).

Many scientific reports showed that the relationship between BF% and body mass index (BMI) is not only age- and gender-dependent, but also ethnic-dependent [7, 14–19]. In children and adolescents, too, the relationship between weight/height and BF% differs among ethnic groups. These differences in the BMI/BF% relationship have urged the World Health Organisation to redefine BMI action points (unpublished data).

Table 1 Composition and density of fat-free mass in age-matched females of different ethnic background and bias using Siri's formula for calculation of body fat percent from density

	f_{water}	$f_{mineral}$	$f_{protein}$	Density (kg/l)	Bias
Blacks	0.735	0.076	0.189	1.1034	-1.1
Whites	0.741	0.071	0.188	1.0988	+0.4
Chinese	0.728	0.079	0.193	1.1072	-3.0
Malays	0.734	0.081	0.185	1.1064	-2.6
Indians	0.729	0.080	0.190	1.1086	-2.8

f_{water}, fraction water in fat-free mass; $f_{mineral}$, fraction mineral in fat-free mass; $f_{protein}$, fraction protein in fat-free mass; *Density*, density of fat-free mass; *Bias*, percent points error if Siri's formula is used; *negative value*, under-estimation; *positive value*, overestimation

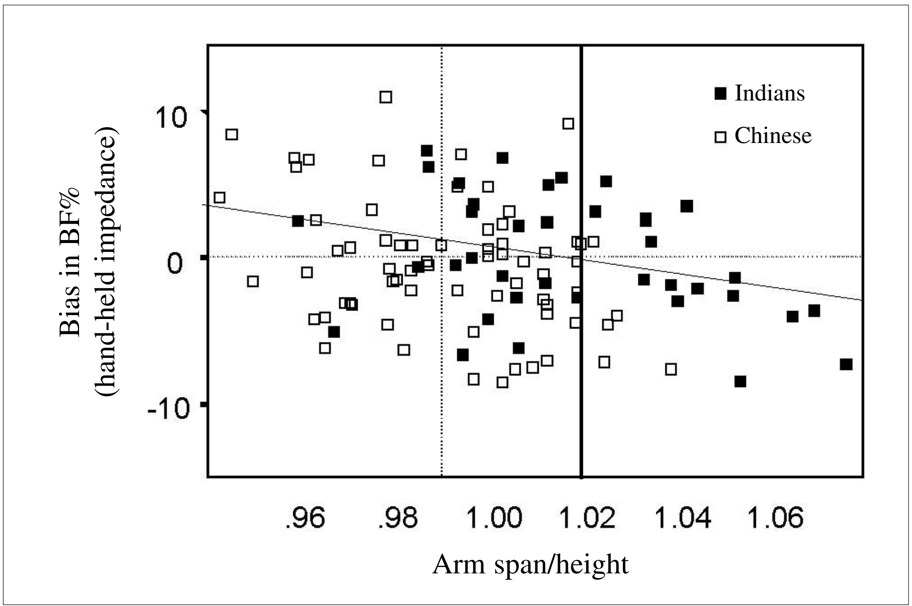

Fig. 1 Bias of predicted body fat percent (BF%) from hand-held impedance in relation to relative arm span in Singapore Chinese and Indians. Bias: measured minus predicted *BF%*; hand-held impedance: body fat measured with OMRON BF306. (Data from [21])

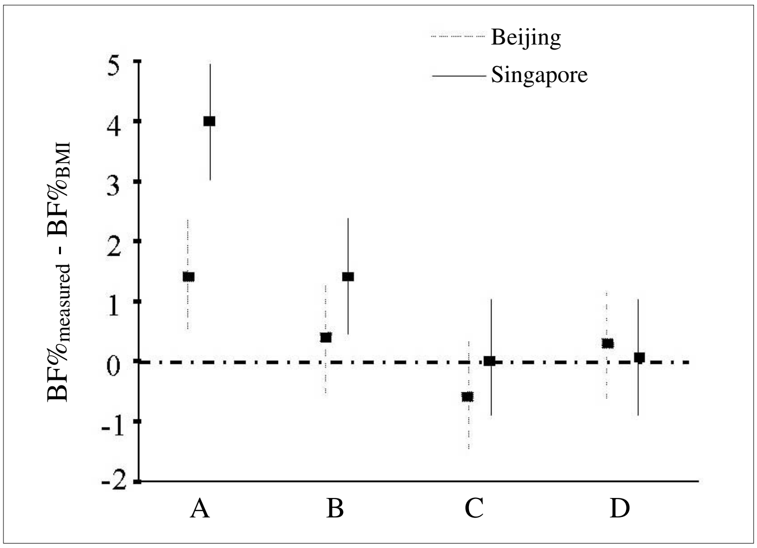

Fig. 2 Bias of predicted body fat percent (*BF%*) from body mass index (*BMI*), age and sex, before and after correction for body build parameters. *A*, No correction; *B*, correction for relative sitting height (leg length); *C*, correction for slenderness (frame size); *D*, corrections for relative sitting height and slenderness; $BF\%_{measured}$, body fat from reference method; $BF\%_{BMI}$, body fat predicted from body mass index [19]. Corrections by analysis of covariance (Dutch group as reference). (Data from [20])

There are differences between ethnic groups in relative leg lengths; for example, blacks have generally longer legs than whites. Chinese and Malays are known to have relatively short legs. In addition, some ethnic groups tend to have smaller frames. It has been shown that relative leg lengths [14, 19] and frame size [19] are factors responsible for ethnic differences in the BMI/BF% relationship. Figure 1 shows the effect of relative leg length and frame size on the predictive validity of BF% from BMI in Beijing Chinese and Singaporean Chinese compared with Dutch Caucasians [20].

Earlier reports showed that total body impedance is largely determined by impedance of the legs and arms. Thus, in subjects with relatively long limbs, impedance values will be high compared to the amount of body water. This means that in subjects or groups of subjects with relatively long limbs, predicted BF% using bioelectrical impedance is likely to be overestimated if the formula used was developed in a population with relatively short limbs. By comparing the validity of predicted BF% from hand-held impedance between female Singapore Chinese and Singapore Indians (Chinese having relatively shorter arms than Indians), it was found that the difference in bias decreased from 1.1% to 0.2% after correcting for the difference in relative arm length between the groups. The effects in males were similar [21]. Figure 2 shows the relationship between bias in predicted BF% from hand-held impedance and relative arm length (arm span).

Studies comparing ethnic groups concluded that there are differences between anthropometric indices of visceral fat and the actual amount of visceral fat as measured by computed tomography or magnetic resonance imaging. Albu et al. [22] showed that for the same amount of body FM, obese black women had significantly less visceral fat and a lower visceral fat-to-subcutaneous fat ratio for any given waist–hip circumference ratio than white women. The relationship between waist circumference and actual amount of visceral fat in children was also different between blacks and whites [23]. Unfortunately, data for other ethnic groups are lacking, but it is likely that these differences also exist across other groups.

In conclusion, indiscriminate and improper use of body composition assumptions across ethnic groups may result in systematic bias. As most information on ethnic differences in body composition is restricted to American-blacks and -whites and sometimes -Asians, there is a need for carefully designed and conducted studies, using appropriate methods, in the Asian Pacific region.

References

1. Wang Z-M, Pierson RN, Heymsfield SB (1992) The five-level model: a new approach to organise body composition research. Am J Clin Nutr 56:19–28
2. Deurenberg P (1992) The assessment of body composition: use and misuse. Annual Report. Nestlé Foundation, Lausanne, pp 35–72
3. Pietrobelli A, Heymsfield SB, Wang ZW, Gallagher D (2001) Multi-component body composition models: recent advances and future directions. Eur J Clin Nutr 55:69–75
4. Deurenberg P, Deurenberg-Yap M (2001) Differences in body composition assumptions across ethnic groups: practical consequences. Curr Opin Clin Nutr Metab Care 4:377–383
5. Forbes GB (1987) Human body composition. Springer, Berlin Heidelberg New York
6. Wang ZM, Deurenberg P, Wang W, Pietrobelli A, Baumgartner RM, Heymsfield SB (1999) Hydration of fat free mass: new physiological modelling approach. Am J Physiol 276 (Endocrinol Metab 39):E995–E1003
7. Wagner DR, Heyward VH (2000) Measures of body composition in blacks and whites: a comparative review. Am J Clin Nutr71:1392–1402
8. Wang J, Thornton JC, Burastero S, Heymsfield SB, Pierson RN (1995) Bioimpedance analysis for estimation of total body water and fat free mass in white, black and Asian adults. Am J Hum Biol 7:33–40
9. Wang J, Russell M, Mazariegos M, Burasteros S, Thornton J, Lichtman S, Heymsfield SB, Pierson RN (1992) Body fat by dual photon absorptiometry: comparisons with traditional methods in Asians, blacks and whites. Am J Hum Biol 4:501–510
10. Werkman A, Deurenberg-Yap M, Schmidt G, Deurenberg P (2000) A comparison between the composition and density of the fat-free mass of young adult Singaporean Chinese and Dutch Caucasian. Ann Nutr Metab 44:235–242
11. Deurenberg-Yap M, Schmidt G, van Staveren WA, Hautvast JGAJ, Deurenberg P (2001) Body fat measurements among Singaporean Chinese, Malays and Indians: a comparative study using a four-compartment model and different two-compartment models. Brit J Nutr 85:491–498
12. Zillikens MC, Conway JM (1990) Anthropometry in blacks: applicability of generalized skinfold equations and differences in fat patterning between blacks and whites. Am J Clin Nutr 52:45–51
13. Malina RM (1996) Regional body composition: age, sex, and ethnic variation. In: Roche AF, Heymsfield SB, Lohman TG (eds) Human body composition. Human Kinetics, Champaign Il, pp 217–256
14. Norgan NG (1995) The assessment of the body composition of populations. In: Davies PSW, Cole TJ, (eds) Body composition techniques in health and disease. Cambridge University Press, Cambridge, pp 195–221
15. Deurenberg P, Yap M, Staveren van WA (1998) Body mass index and percent body fat: a meta-analysis among different ethnic groups. Int J Obesity 22:1164–1171
16. Ko GTC, Tang J, Chan JCN, Sung R, Wu MMF, Wai HPS, Chen R (2001) Lower BMI cut-off value to define obesity in Hong Kong Chinese: an analysis based on body fat assessment by bioelectrical impedance. Brit J Nutr 85:239–242
17. Deurenberg-Yap M, Schmidt G, Staveren van WA, Deurenberg P (2000) The paradox of low body mass index and high body fat percent among Chinese, Malays and Indians in Singapore. Int J Obesity 24:1011–1017
18. Swinburn BA, Ley SJ, Carmichael HE, Plank LD (1999) Body size and composition in Polynesians. Int J Obesity 23:1178–1183
19. Deurenberg P, Weststrate JA, Seidall JC (1991) Body mass index as a measure of body fatness: age and sex specific prediction formulas. Br J Nutr 65:105–114
20. Deurenberg P, Deurenberg-Yap M, Wang J, Lin Fu Po, Schmidt G (1999) The impact of body build on the relationship between body mass index and body fat percent. Int J Obesity 23:537–542
21. Deurenberg P, Deurenberg-Yap M (2002) Validation of skinfold thickness and hand-held impedance measurements for estimation of body fat percentage among Singaporean Chinese, Malays and Indians. Asia Pacific J Clin Nutr 11:1–7
22. Albu JB, Murphy L, Frager DH, Johnson JA, Pi-Sunyer FX (1997) Visceral fat and race-dependent health risks in obese nondiabetic premenopausal women. Diabetes 46:456–462
23. Goran MI, Nagy TR, Treuth MS, Trowbridge C, Dezenberg C, McGloin A, Gower BA (1997) Visceral fat in white and African American pre-pubertal children. Am J Clin Nutr 65:1703–1708