Chapter 4

Variations and errors in anthropometric measurement and body composition prediction

Variations and errors can occur in anthropometric measurements which may affect the precision, accuracy and validity of the measurements as well as predictive capability. The following five major sources of error are significant: (1) measurement errors, both random and systemic, (2) alterations in the composition and physical properties of certain tissue, (3) the use of invalid assumptions in the derivation of body composition from anthropometric measurements, (4) ethnic differences, and (5) age spectrum effects.[1-4]

1. Measurement errors

1.1 Random measurement errors and precision

Random errors can generate a deviation from the correct result due to chance alone. They lead to measurements that are imprecise in an unpredictable way, resulting in less certain conclusions. They reduce the precision of a measurement by increasing the variability of the mean. They usually do not influence the mean or median value. Anthropometric measurement errors can be minimized by training personnel to use standardized techniques and precise, correctly calibrated instruments. Firm establishment in each measurement technique prior to use and multiple measurements on each individual are suggested for precise and accurate increments. Poor precision is often reflected within examiner error, but errors between examiners may be significant in surveys with multiple examiners. The precision of a measurement technique can be assessed by calculating the following description parameters, technical error of the measurement (TEM), percent technical error (%TEM) and coefficient of reliability (R).[2] These parameters can be calculated for each anthropometric measurement technique from repeated measurements on each subject made within a few minutes to avoid physiological fluctuations. A minimum of ten subjects is recommended for testing these reliability.[2]

1.1.1. Technical error of the measurement (TEM)

Technical error of the measurement is age dependent, and the value is also related to the anthropometric characteristics of the study group. The calculation varies according to the number of replicated measurements made. This measurement error calculation is revealed by the formulas below: (1) for two measurements and (2) for more than two measurements.[2] However, the size of the measurement also influences the size of the associated TEM, so that comparisons of precision of different anthropometric measures using TEM cannot be easily made.[5]

For two measurements $$\mathrm{TEM} = \sqrt{\frac{(\sum \mathrm{Diff}^2)}{2\mathrm{N}}}$$ ....(1)

Where Diff= the difference between two measurements
N= number of subjects

For more than two measurements…….$\mathrm{TEM} = \sqrt{\frac{\sum_1^N\left[\left(\sum_1^K M^2\right)-\left(\frac{\left(\sum_1^K M\right)^2}{K}\right)\right]}{[N(K-1)]}}$ ………(2)

Where N = number of subjects

K = the number of determination of the variable taken on each subject

M_n = the n^{th} replicate of the measurement where, n varies from 1 to K

1.1.2. Percent technical error (%TEM)

The use of percentage TEM has been recommended to overcome the difficulty of the TEM being dependent on the size of the original measurement. The percentage of technical error on the measurement is analogous to the coefficient of variation and is calculated as formula (3). The advantage of this method can be used to make direct comparisons of all types of anthropometric measurements. However, it cannot be used when more than one examiner is involved, as then both within and between examiner errors are involved.[5]

$$\%\mathrm{TEM} = \left(\frac{\mathrm{TEM}}{\mathrm{mean}}\right) \times 100\% \text{......(3)}$$

1.1.3. Coefficient of reliability (R)

An alternative approach that is widely used for comparing measurement errors among anthropometric measurements is to calculate the coefficient of reliability (R), which range from 0 to 1. This coefficient can be calculated using the following equation (4).

$$R = 1 - \left(\frac{(\mathrm{TEM})^2}{s^2}\right) \text{............(4)}$$

Where s^2 is the between subject variance.

The coefficient indicates the proportion of between subject variance in a measured population which is free from measurement error. Therefore, a measurement with R=0.95 indicates that 95% of the variance is due to factors other than measurement error. Coefficients of reliability can be used to compare the relative reliability of different anthropometric measurements, and the same measurements in different age groups, as well as for calculating sample sizes in anthropometric surveys.

1.2 Systemic measurement errors and accuracy

Systemic measurement errors affect the accuracy or the degree to which the measurements depart from true values. These errors arise from examiner error resulting from inadequate training, instrument error, and difficulties in taking the measurement, such as varying in skinfold thickness measurement, as well as on the selection process of samples. In addition, the timing of some anthropometric measurements of body size, body circumferences and compositions are also known to be critical and have diurnal variation.

However, the determination of accuracy in anthropometry is difficult because the correct value of any anthropometric measurement is never known. The experts have recommended targets for anthropometric assessment using repeated measurements protocol that can be used for training anthropometries for length, height, weight, arm circumference and skinfolds shown in Table 4.1 .[2]

Table 4.1 Evaluation of measurement error in anthropometric measurements.

Measurement	Trainee – trainer difference		
	Good	Fair	Poor
High or length (mm)	0 – 5	6 – 9	10 – 19
Weight (kg)	0 – 0.1	0.2	0.3 – 0.4
Arm circumference (mm)	0 – 5	6 – 9	10 – 19
Skinfolds (any) (mm)	0 – 0.9	1.0 – 1.9	2.0 – 4.9

2. Variations and errors from change in tissue composition and properties

Variations in the composition measurement and physical properties of certain tissues may occur in both healthy and diseased subjects. For example in healthy individual, body weight may be affected by variations in tissue hydration with the menstrual cycle in female.[1] Skinfold thickness measurements may be influenced by variations in compressibility and skin thickness with age, gender, and the level of tissue hydration.[2,5] For example, repeated measurements of skinfolds may actually decrease the accuracy of skinfolds because later measurements are more compressed due to the expulsion of water from the adipose tissue at the site of the earlier measurement.[5] In addition, during aging, de-mineralization of the bone and changes in body water may result in a decrease in the density of the fat free mass.[6] Generally, anthropometric measurements are unable to accurate to account for these effects.

3. Invalid model and errors in body composition

Invalid assumptions may lead to erroneous estimates of body composition when these are derived from anthropometric measurements, especially in obese or elderly patients and those with protein energy malnutrition or certain disease states. For example, use of skinfold thickness measurements to estimate total body fat assumes that (1) the thickness of the subcutaneous adipose tissue reflects a constant proportion of the total body fat and (2) the sites selected represent the average thickness of the subcutaneous adipose tissue. In fact, the relationship between subcutaneous and internal fat is nonlinear and varies with body weight, age, and the disease state. Very lean subjects have a smaller proportion of body fat deposited subcutaneously than do obese subjects and there is the probability of a shift of fat storage from subcutaneous to the deep visceral sites in malnourished persons. Variations in the distribution of subcutaneous fat also occur with age, sex and ethinicity.[7-8]

One of the most common anthropometric parameters for total body fat prediction is BMI. However, there are some limitations. First, the proportions of BMI change with the age and age spectrum.[3] Second, race or ethnic and gender differences play an important role in modeling prediction. Of these, there are interactions together when using BMI to predict body fat when using standard methods.[9] The following figure below shows the impact of the age spectrum which affects the modeling prediction error (Figure 4.1).[3] Details of this study are proposed in appendix D.

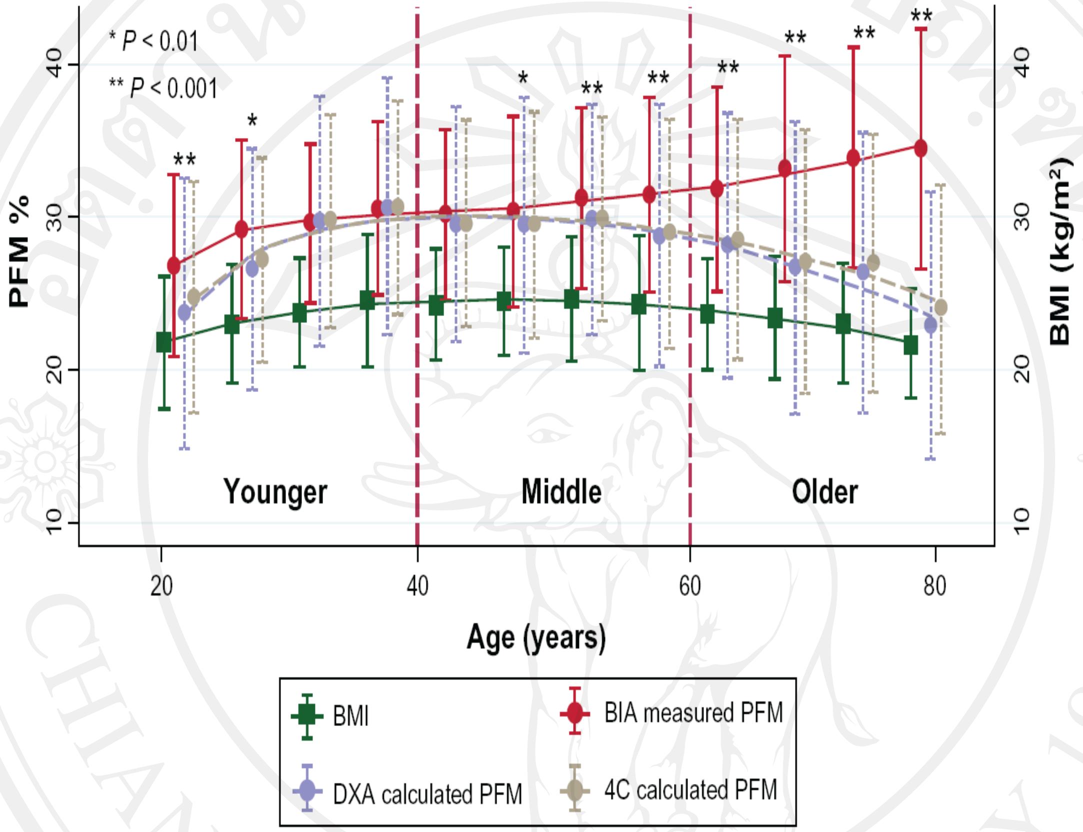

Figure 4.1 Comparing measured BIA, calculated PFM and BMI demonstrated by mean ± S.D. in each age group[3]
Abbreviation: BMI, body mass index; BIA, bioelectrical impedance analysis; PFM, percentage of fat mass; DXA, dual energy X ray absorptiometry; 4C, four compartment method (From Chittawatanarat et al., Clin Interv Aging 2011;6:285-94, with permission of the authors and of the Dove Medical Press)

4. Effects of ethnicity to anthropometric variations and interpretations

Ethnicity is one of the important parameters that should be concerned during the interpretation of anthropometric results. As previously mentioned, the BMI is independent of height when compared with weight alone. However, body stature and shape is different between races and might interfere with the BMI interpretation. The most common index to define the differences of body stature in those whose legs are shorter or longer than might be expected for their height is Cormic index, which is defined as the ratio of sitting height (crown-rump length) to height (SH/H).[10] This index provides a measure of the relative length of trunk (sitting height) to the overall of stature between individuals and groups and is used for comparison between ethnic differences. A typical of this index in Europeans and Indo-Mediterranean is approximately 0.52 – 0.53 but populations in Western Pacific regions have values of 0.54, and African populations somewhat lower values of 0.51 – 0.52 (Figure 4.2).[10]

Interpreting the BMI in each ethnic difference as a surrogate parameter to estimate body fat should be used with caution. Deurenberg et al performed meta-analysis among difference ethnic groups which demonstrated that the relationship between percent body fat and BMI differs in the ethnic groups studied. For the same level of body fat, age and gender, American Blacks have a 1.3 kg/m^2 and Polynesians a 4.5 kg/m^2 lower BMI compared to Caucasians. By contrast, in Chinese, Ethiopians, Indonesians and Thais BMIs are 1.9, 4.6, 3.2 and 2.9 kg/m^2 lower compared to Caucasians, respectively. Slight differences in the relationship between the percent of body fat and BMI of American Caucasians and European Caucasians were also found. The differences found in the body fat/BMI relationship in different ethnic groups could be due to differences in energy balance as well as to differences in body build (Figure 4.3).[4]

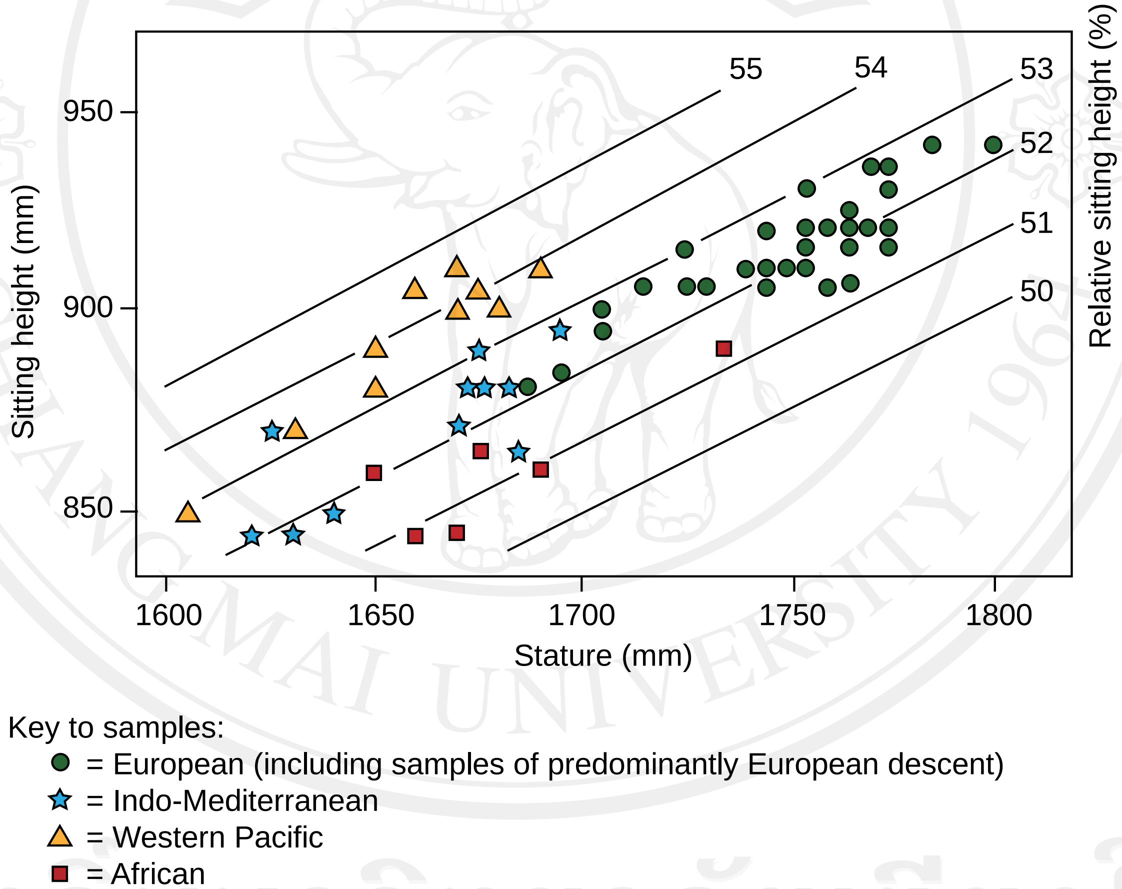

Figure 4.2 Ethnic differences in the relationship between average sitting height and average stature in adult men[10] (From WHO Expert Committee on Physical Status, WHO Technical Report Series 854,page 355, with permission of WHO)

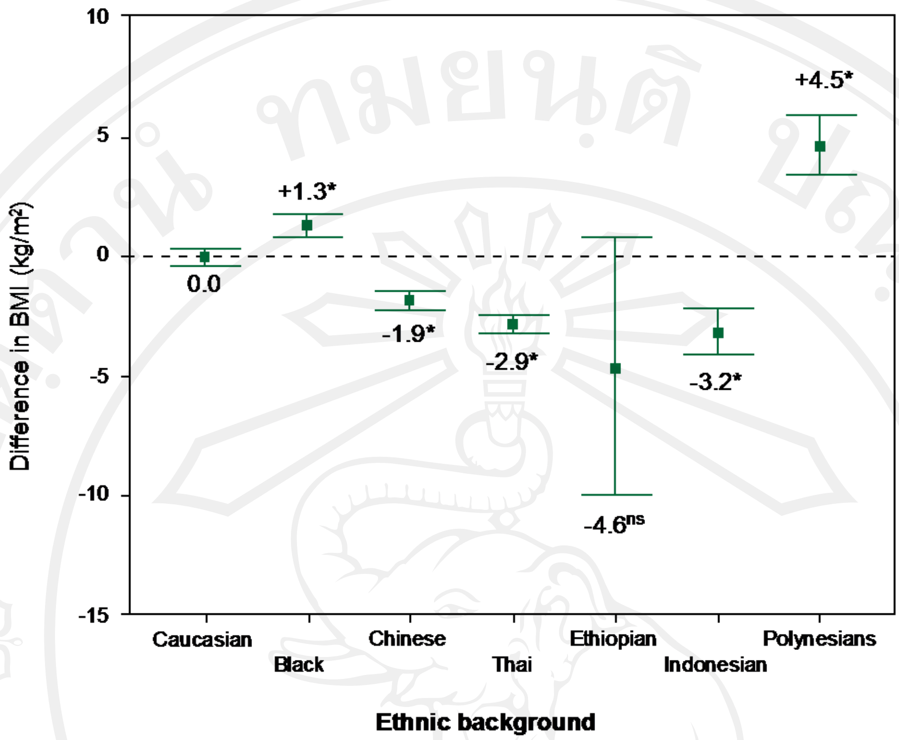

Figure 4.3 Ethnics differences in body mass index (mean and 95% confidence interval) which reflect equal levels of body fat, adjusted for age and sex. The reference means are relative to the results for Caucasians (Reference to 0.0)[4] Note: * ,p<0.05; ns, No significant. (From Deurenberg et al., Int J Obes Relat Metab Disord 1998;22:1164-71, with permission of the authors and of the Nature Publishing Group)

5. Effects of age and age spectrum in body compositions

The authors performed a survey using bioelectrical impedance (BIA) for body composition determination. A total of 2324 Thai volunteers were included in this study which demonstrated the coefficient alteration of body composition dependent on age and age spectrum (Table 4.2, Figure 4.4-4.5).[3] Details of this study are shown in Appendix D.

Table 4.2 Coefficient alteration between quarters of age adjusted by gender and BMI[3]

Parameter	<60 years†	≥ 60 years†	Difference†	*p* value
PFM	0.09(0.07/0.11)	0.26(0.21/0.31)	0.18(0.13/0.23)	<0.01
PFFM	-0.09(-0.11/-0.07)	-0.26(-0.31/-0.21)	-0.18(-0.23/-0.13)	<0.01
FMI	0.02(0.01/0.02)	0.06 (0.05/0.07)	0.04(0.03/0.06)	<0.01
FFMI	-0.02(-0.02/-0.01)	-0.06(-0.07/-0.05)	-0.05(-0.06/-0.03)	<0.01
PFMR($x10^{-2}$)	0.32(0.23/0.41)	1.20 (0.95/1.46)	0.97 (0.73/1.21)	<0.01
PFFMR($x10^{-2}$)	-0.61(-0.73/-0.49)	-0.87 (-1.13/-0.60)	-0.22 (-0.49/0.04)	0.11

Note: † Regression coefficient (95% confidence interval: lower/upper value)
Abbreviation: PFM, Percentage of fat mass; PFFM, Percentage fat free mass; FMI, Fat mass index; FFMI, Fat free mass index; PFMR, Percentage fat mass to BMI ratio; PFFMR, Percentage fat free mass to BMI ratio

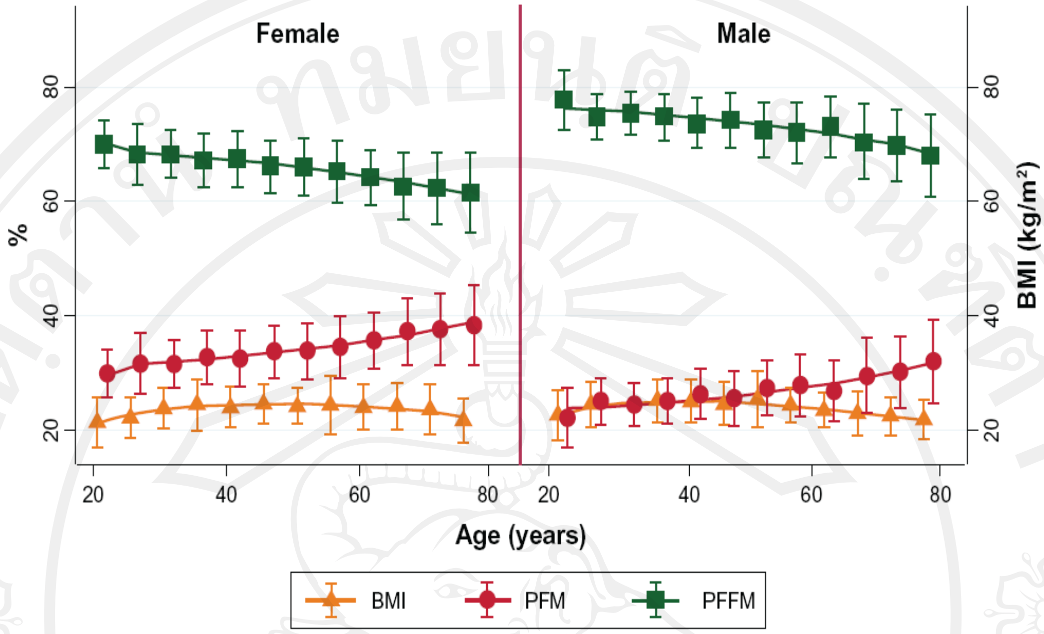

Figure 4.4 Relationship of BMI, percentage body fat, and percentage lean body mass demonstrated by mean ± standard deviation over age in each gender.[3]
Abbreviations: BMI, body mass index; PFM, percentage of fat mass; PFFM, percentage of fat free mass.
(From Chittawatanarat et al., Clin Interv Aging 2011;6:285-94, with permission of the authors and of the Dove Medical Press)

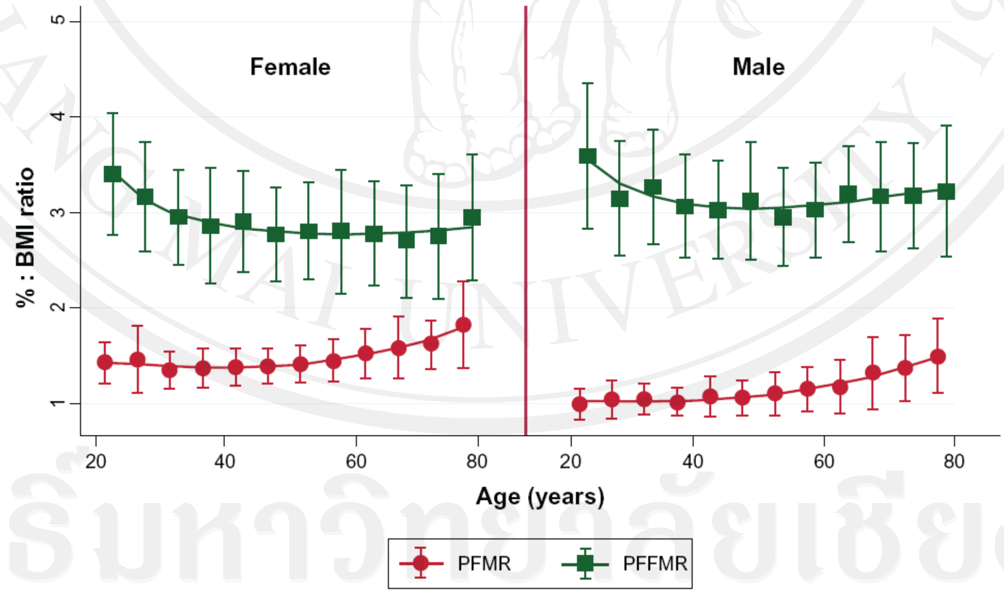

Figure 4.5 Relationship of PFMR with PFFMR demonstrated by mean ± standard deviation over age in each gender.[3]
Abbreviations: PFMR, percentage of fat mass to BMI ratio; PFFMR, percentage of fat free mass to BMI ratio.
(From Chittawatanarat et al., Clin Interv Aging 2011;6:285-94, with permission of the authors and of the Dove Medical Press)

In addition, body fat has been affected by the age spectrum in younger (18-39 years), middle (40-59 years) and older (≥60 years) people when adjusted utilizing the multivariable model by gender, BMI and weight status (Table 4.3).[3]

Table 4.3 Multivariable regression coefficient of parameters associated to percentage body fat measured by BIA[3]

Parameters	Younger†	p	Middle†	p	Older†	p	Total†	p
Female	7.92 (7.14/8.69)	<0.01	7.41 (6.83/7.98)	<0.01	7.61 (6.88/8.35)	<0.01	7.44 (7.02/7.85)	<0.01
Age (year)	0.07 (0.01/0.12)	0.02	0.13 (0.08/0.18)	<0.01	0.26 (0.21/0.31)	<0.01	0.15 (0.14/0.17)	<0.01
BMI	0.57 (0.48/0.66)	<0.01	0.66 (0.59/0.74)	<0.01	0.42 (0.32/0.52)	<0.01	0.50 (0.45/0.55)	<0.01
Underweight ‡	-1.41 (-0.06/-2.77)	0.04	-2.29 (-4.05/-0.53)	0.11	-1.46 (-2.72/-0.20)	0.02	-1.04 (-1.86/-0.22)	0.13
Overweight ‡	3.48 (2.54/4.42)	<0.01	3.68 (3.04 -4.32)	<0.01	1.85 (0.93 – 2.78)	<0.01	2.75 (2.26/3.24)	<0.01
Obesity‡	6.59 (5.19/8.00)	<0.01	7.50 (6.28/8.71)	<0.01	5.68 (4.02/7.32)	<0.01	6.48 (5.62/7.35)	<0.01

Note: † Regression coefficient (95% confidence interval: lower /upper value), ‡ compare to normal status as reference

Abbreviation: BMI, Body mass index; BIA, Bioelectrical impedance analysis

6. Summary

Variations and errors of anthropometric measurements can occur in many aspects of measurement. The interpretation of these parameter may have concerns for appropriate validity and precision when utilized for clinical application.

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