

Original Paper Relationships Between Indices of Arm Anthropometry, Bioimpedance, and Laboratory in Maintenance Hemodialysis Patients

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Abstract

Background Maintenance hemodialysis patients often experience protein-calorie malnutrition. Our aim is to evaluate the independent prediction accuracy of bioelectrical impedance analysis derived variables by the measurements of upper arm anthropometry and clinical laboratory indexes for evaluation of nutritional status of hemodialysis patients. Furthermore, the relationship between measurements of upper arm anthropometry and clinical laboratory indexes and cross-sectional evaluation of the prevalence of malnutrition with the use of the norms and thresholds were done.

Methods In a cross-sectional survey of 32 stable hemodialysis patients (aged 28 to 82 years) in hemodialysis unit of Taipei Municipal Zhongxiao Hospital, we evaluated measurements of upper arm anthropometry with measurements of single frequency bioelectrical impedance analysis and clinical laboratory indexes.

Results The comparisons between measurements of upper arm anthropometry with measurements of single frequency bioelectrical impedance analysis and some of clinical laboratory indexes were statistically significant. This study further found that both mid-arm fat area and triceps skin-fold thickness were independent contributors to percent fat mass after adjustment for body mass index and gender in the multiple regression models. This study also demonstrated that mid-arm muscle circumference, or mid-arm muscle area, or corrected mid-arm muscle area independently predicted height normalized indices of fat-free mass respectively after adjustment for body mass index and gender in the multiple regression models. The prevalence of protein wasting measured by mid-arm muscle circumference (50%) appears to be equivalent to that measured by serum albumin concentration (50%).

Conclusions Mid-arm muscle and fat variables by upper arm anthropometry correlated with nutritional variables of single frequency bioelectrical impedance analysis and clinical laboratory indexes. Mid-arm muscle and fat variables by upper arm anthropometry were independent predictors of body composition regarding height-normalized indices of fat-free mass and percent fat mass of hemodialysis patients even after adjustment of gender and BMI.

Introduction

Bioelectrical impedance analysis (BIA) has been validated as an easy and safe method for measurement of body compartments in maintenance hemodialysis (MHD) patients [1], though BIA is not a gold standard modality to measure body composition. And, reliable fat free mass (FFM) and fat mass estimates should only be derived while patients are at normal hydration. Timing of the post-hemodialysis measurement is important since hydration status is changed if patients have water intake. Thus, BIA must be used immediately following a hemodialysis session at the time of the dry weight goal approximated with blood pressure indices.

A previous study showed that corrected mid-arm muscle area (cMAMA) was significantly associated with an index of total muscle mass in non-renal patients[2]. Furthermore, a previous paper found that triceps

skinfold thickness (TSFT) and MAMC (mid-arm muscle circumference) in MHD patients significantly correlated with percent fat mass and FFM, **respectively**, from biochemical determinations[3].

Because FFM could be misleading without normalization to body size, height-normalized indices of fat-free mass (FFMI) has been suggested as a surrogate of indicating FFM [4]. A previous paper showed that steady-state serum leptin levels, a marker of adiposity, had stronger association with percent fat mass than with body fat mass or body mass index (BMI) in Taiwanese hemodialysis subjects without diabetes. Percent fat mass was used as a substitute of fat mass in this previous paper because it could sensitively reflect changes in fat mass of MHD patients [5]: The following studies report that body composition is related to outcomes of MHD patients. For example, a previous study showed that a higher FFMI was independently correlated with a lower risk of cardiovascular mortality in MHD patients [6]. Thus predictors of FFMI could be associated with a lower risk of cardiovascular death. This previous study also demonstrated that a lower fat mass index was independently correlated with a higher risk of all-cause and non-cardiovascular death in MHD patients [6]. Phase angle is one of the most helpful nutritional biomarkers derived from bioimpedance at 50 kHz. Maggiore et al. reported, in a 131 MHD patient series, that MAMC correlated with post hemodialysis phase angle and the latter was strongly associated with patient survival [7]. Another study revealed the independent effect of low percent fat mass both at baseline and over time on higher mortality in MHD patients [8]. But, MHD patients with sarcopenic obesity (high body mass index and low muscle mass) have increased mortality [9].

We hypothesized that mid-arm muscle and fat variables by upper arm anthropometry in MHD patients were independent predictors of FFMI and percent fat mass, respectively. Thus, we measured the performance of anthropometric methods and biochemical indexes in the prediction of bioelectrical impedance.

Materials And Methods

Our study is a prospective study, our dieticians witnessed verbal consent of evaluation of nutritional status. The department of teaching and research, the counterpart of ethical committee, of Taipei Municipal Zhongxiao Hospital approved this research study in 2003. Because our study was a non-invasive one and it only involved measurements of anthropometry and single bioelectric impedance analysis, consent was verbal. The department of teaching and research approved the whole study, including this consent procedure. The merger of ten community hospitals into one union has made the Taipei City Hospital the largest healthcare institution in Northern Taiwan in January 1, 2005. The department of teaching and research of Taipei City Hospital also approved this research study in June, 2020 with the case number 10939. Institutional review board of Taipei City hospital approved this research with the case number TCHIRB-10907008-E. The fasted blood sample and analyses collected for routine medical purposes. All of the data were anonymized/de-identified prior to access and analysis. Any of the authors did not have access to identifying patient information.

Calculation of sample size required for linear multiple regression models from squared correlation coefficients

A previous study provided correlation coefficients [3]. Triceps skinfold thickness ($R=0.84$; $P< 0.001$) significantly associated with percent fat mass; Mid-arm muscle circumference significantly associated with lean body mass ($R=0.79$; $P< 0.001$). The maximum number of predictors in the linear regression models of table 3 and table 4 is five. We chose a desirable significant level of 0.05. Using these data and [G*Power 3.1.9.2](#), the minimal sample size required for building a linear regression model was about 30.

Participants

The study subjects were 32 chronic renal failure patients receiving regular hemodialysis in the renal unit of Taipei Municipal Zhongxiao Hospital from July 2003 to August 2004. Eighteen diabetic patients were recruited in this research. The study subjects were selected because they agreed to receive the measurements. Our dieticians witnessed oral consent for the measurements. All patients were without active medical or surgical disease, and none were taking corticosteroids that could lead to lean body mass depletion.

Variables of BIA, Upper Arm Anthropometry and Laboratory Indexes

Fasted blood samples were taken and sent to our laboratory for the following analyses: serum albumin, total protein, blood urea nitrogen, creatinine, cholesterol, and triglyceride. Serum albumin levels were measured by the bromocresol green (BCG) method.

A well-trained dietician carried out the following measurements on each patient in triplicate after a dialytic session on an outpatient basis: height, weight, mid-arm circumference (MAC), TSFT, percent fat mass, total body water (TBW), and FFM. The dry body weight of each patient was individually evaluated based on the cardiothoracic ratio, pretibial edema, facial edema, pulmonary edema, jugular vein pressure, and a decrease in blood pressure during the hemodialysis session or inter-dialytic period.

Measurements of percent fat mass, TBW, FFM were obtained with single-frequency BIA (BA-200, Mesmed System Co., Ltd.). The procedure of BA-200 is simple and easy. The BA-200 was done with the patient relaxed in a sitting posture with legs separated and arms abducted from the body. Measurements were done on the nonvascular access site. The proximal (detector) electrodes were set on the leg and forearm. A low-amplitude, single frequency, imperceptible alternating current ($800\mu\text{A}$ at 50 kHz) was applied via the source electrodes at the wrist and ankle. The method for estimating total body water is a BIA estimate.

Height was estimated to an accuracy of 0.1 cm by employing a wall-mounted stadiometer (Holstain, Crymych, UK). Weight was recorded utilizing a digital scale precise to 0.02 kg (FW-122 series, floor scale, maximum measured weight 122 kg). Triceps skin-fold thickness of the arm without a vascular access was measured to the nearest 0.5 mm with a Lange skin-fold Caliper, calibrated to apply a pressure of 10 g/mm^2 of jaw surface. A flexible plastic-coated tape was applied to measure MAC of the non-access arm to the nearest 0.1cm with sufficient pressure to touch, but not indent the skin. From these measurements, the following variables were computed: MAMC (cm), mid-arm area (MAA; mm^2), mid-arm muscle area (MAMA, mm^2), cMAMA (mm^2), mid-arm fat area (MAFA, mm^2), BMI (kg/m^2), and FFMI (kg/m^2) [2].

Formulae for these are as follows [2]:

$$\text{MAMC (cm)} = \text{MAC (cm)} - (\pi \times \text{TSFT (mm)} / 10)$$

$$\text{MAA (mm}^2\text{)} = [\text{MAC (mm)}]^2 \div 4\pi$$

$$\text{MAMA (mm}^2\text{)} = [\text{MAC (mm)} - \pi \times \text{TSFT (mm)}]^2 \div 4\pi$$

$$\text{MAFA (mm}^2\text{)} = \text{MAA} - \text{MAMA} = [\text{MAC (mm)}]^2 \div 4\pi - [\text{MAC (mm)} - \pi \times \text{TSFT (mm)}]^2 \div 4\pi$$

$$\text{Corrected MAMA (males, mm}^2\text{)} = [\text{MAC (mm)} - \pi \times \text{TSFT (mm)}]^2 \div 4\pi - 1000$$

$$\text{Corrected MAMA (female, mm}^2\text{)} = [\text{MAC (mm)} - \pi \times \text{TSFT (mm)}]^2 \div 4\pi - 650$$

Statistical Analysis

Data were evaluated utilizing SPSS 15.0 for Windows. Quantitative results were presented as mean or median. Because of considerable skewness in the data separated by gender, comparisons were made using Mann Whitney U tests. We used Pearson correlation to assess the relationship among derived estimates by BIA and measurements by upper arm anthropometry and clinical parameters. Because BMI includes fat mass and lean mass in its measurement, we used BMI in the linear regression models for comparison. Multiple regressions were used to quantify the relative importance of variables of upper arm anthropometry, biochemical parameters, gender, and BMI in the prediction of body composition obtained from BIA. A value of $P < 0.05$ was used to suggest statistical significance. We checked variance inflation factor, condition index and eigen value for collinearity. Mid-arm muscle circumference, MAC, MAMA, cMAMA, and predialysis serum creatinine had collinearity. Mid-arm fat area, MAC and TSFT had collinearity. Height and BMI had collinearity. Thus, we treated collinearity by putting them separately in the model and eliminating the variable, which caused inaccurate computations of the regression coefficients.

Test-Retest Reliability of Total Body Water

Because the same operator obtained the measurement of total body water, we can avoid operator-dependent (inter-observer) random measurement error. For the test-retest reliability trials, the intra-class correlation coefficients (Rho) of repeated total body water with 1-way random model and its 95% confidence interval were 0.997 (0.995-0.998).

The norms or the thresholds of upper arm anthropometry, clinical parameters and BIA derived values

The data set of the Second National Health Survey (1986-1988) of a representative pool of the healthy Taiwanese population provided percentiles for TSFT, MAC and MAMC of Taiwanese [10]. The survey is of apparently 20653 healthy subjects (10398 females, 10255 male) and stratified by different age groups. As a general rule, measurements below the 10th percentile of normal population and below the 50th percentile of MHD patients are considered to represent significant malnutrition. Furthermore, racial distinction in body composition and body proportions also exist. A previous study pointed out upper arm anthropometric standards established for the United States population of whites [11]. Another publication provided age,

gender-, diabetics-, race- and dialysis treatment modality- specific reference norms for TSFT and MAC of the stable dialysis population [12]. Patients with percent fat mass smaller than 10 % were defined as energy malnutrition [13]. Based on WHO definition, overweight was defined as a BMI more than 23 kg/m², obesity as a BMI more than 25 kg/m², and underweight as a BMI below 18.5 kg/m² in adult Asians. However, evaluation of prevalence of overweight, obesity or underweight, based on WHO definition for a general population, may be not proper for HD population. Based on the data from healthy population of whites, FFMI (kg/m²) was “low” at <16.7 (men) and < 14.6 (women); “normal” between 16.7 and 19.8 (men) and 14.6 and 16.8 (women); and “high” at >19.8 (men) and > 16.8 (women) [4]. Ten Percentile values of FFMI (kg/m²) for the healthy population of whites by different ages categories were as follows [13]: between age 18 – 34 were 17.2(men) and 14.1(women); between age 35-54 were 17.6 (men) and 14.7 (women); between age 55-74 were 17.6(men) and 14.6 (women); above age 75 were 16.9 (men) and 13.7(women). Pre-dialysis serum albumin concentrations < 3.8 g/dl reflect visceral protein malnutrition [13].

Results

The main characteristics of the study subjects are shown in the Table 1. The etiologies of chronic renal failure were diabetic nephropathy (n=18), chronic glomerulonephritis (n= 6), obstructive nephropathy (n= 4), gout nephropathy (n= 3), and hypertensive nephrosclerosis (n=1).

Correlation Study

Height- normalized indices of fat –free mass significantly correlated with MAMA, MAMC, cMAMA, gender, BMI and MAC (Table 2a). In addition, percent fat mass significantly correlated with MAFA, TSFT, BMI, gender, MAC and height (Table 2a). No significant correlations were noted between FFMI and serum creatinine concentrations, or serum albumin concentrations, or serum total protein values.

Height-normalized indices of fat- free mass were more strongly correlated with MAMA (r=0.748; P< 0.001) than with MAMC (r=0.739; P< 0.001), or with cMAMA (r=0.656; P <0.001) in the study subjects. Similarly, percent fat mass was more strongly associated with MAFA (r=0.718; P< 0.001) than with TSFT (r=0.703; P <0.001) in the study subjects (FIG 1A, 1B, 1C, 1D, 1E).

Mid-arm muscle circumference, or MAMA, or cMAMA were associated more closely with serum creatinine levels than with serum albumin concentrations, respectively. Mid-arm circumference varied more closely with serum creatinine concentrations than with serum albumin concentrations or with serum total protein values. Significant correlations were found between serum triglyceride levels and TSFT and MAFA (Table 2b).

Multiple Regression Study

Mid-arm muscle circumference or MAMA or cMAMA were statistically significant predictors of FFMI after adjustment for gender and BMI (Table 3b, 3c and 3d). Mid-arm fat area and TSFT were statistically significant predictors of percent fat mass after adjustment for BMI and gender (Table 4b, 4c). After

adjustment for BMI, MAC was not statistically significant in the prediction of FFMI or percent fat mass (Table 3a, 4a).

Evaluation of Rates of Malnutrition with Use of Norms and Thresholds

Protein-energy malnutrition (MAC lower the 10th percentile of the normal population) was found in 11 patients (34%). Protein malnutrition (MAMC lower the 10th percentile of the normal population) was found in 16 patients (50%). Using serum albumin levels < 3.8 g/dl as a cut-off point, 50 % (16/32) of patients was visceral protein malnutrition. Energy wasting (percent fat mass smaller than 10 %) was found in 4 patients (12.5%). Underweight (BMI below 18.5 kg/m²) was found in 2 patients (6.25%). Energy malnutrition (TSFT lower the 10th percentile of the normal) was found in 1 patient (3%).

Post-hoc Calculation of Statistical Power for Multiple Regression Study

We calculated the observed power for our multiple regression study, given the observed probability level (p=0.05), the number of predictors, the observed R², and the sample size (n=32). We derived the observed power of multiple regression models in Table 3a, 3b, 3c, 3d, 4a, 4b, and 4c. The values of the observed power were all approximated as 1.

Discussion

There are two types of protein- calorie wasting in MHD patients. The first type of protein-calorie wasting occurs in MHD patients who demonstrate anorexia/uremic symptomatology. When faced with lack of nutrition, humans oxidize endogenous fuel in the form of glycogen (within the liver and muscle cells), skeletal muscle protein, adipose tissue triglyceride, and metabolically active organs including liver, intestine and kidney [14]. Because whole body glycogen storage is more limited than protein or fat reserves, changes in body glycogen stores are not considered. In spite of adequate intake, second type protein-calorie wasting presents with loss of FFM and low serum protein levels is caused by other conditions, such as nonspecific inflammatory processes; inter-current catabolic illness; acidemia; activation of the ubiquitin -proteasome system and resistance to anabolic hormones. Ubiquitin proteasome pathway is responsible for the breakdown of myofibrillar proteins [15]. And, plasma proteins are taken up by endocytosis and degraded within lysosomes.

From multiple regression studies, MAMA (partial r² = 0.080), or MAMC (partial r² = 0.075), or cMAMA (partial r² = 0.073), was an independent predictor of FFMI after adjustment for gender and BMI (partial r² = 0.194). Body composition could be divided into 2 compartments: fat mass and FFM. Fat free mass may be further be partitioned into bone, skeletal muscles and non-skeletal muscle soft tissues. Mid-arm muscle circumference is a one-dimensional measurement of upper arm muscle mass. Corrected mid-arm muscle area is a two-dimensional measurement of upper arm muscle mass. Mid-arm muscle area involves a subtracted constant resulted from inclusion of non-skeletal muscle soft tissues and bone [2]. This explained why height-normalized indices of fat- free mass were more strongly correlated with MAMA than with MAMC, or with cMAMA in the study subjects. The results of multiple regression indicated that the relationship between indicators of upper arm muscle measured by upper arm anthropometry and BIA determined FFMI

was beyond containment relations. These data can be explained as follows. First, approximately half of our study subjects wasted muscle mass because MAMC lower the 10th percentile of the normal population was found in 16 patients (50%). Second, upper arm muscle mass is a nutritional active portion of FFM. A regional lean tissue composition study measured by dual energy x-ray absorptiometry also demonstrated that lean body mass depletion was due to loss of limb lean tissue (especially arm) with preservation of trunk lean tissue [16]. Third, the regional distribution of lean body mass may be distorted in some MHD patients, resulting in a breakdown in the relationship between variables of upper arm anthropometry and measurements of BIA.

There are generally two types of fat mass: visceral fat mass (surrounding organs) and *subcutaneous* fat mass (beneath the skin). Subcutaneous fat mass is further divided into abdominal *subcutaneous* and non-abdominal subcutaneous ones. The regional distribution of subcutaneous fat area and the ratio of subcutaneous to visceral fat area may be different in MHD patients. Even though TSFT is a one-dimensional measurement of not abdominal subcutaneous fat mass, and MAFA is a two-dimensional measurement of not abdominal subcutaneous fat mass, MAFA (partial $r^2= 0.089$) or TSFT (partial $r^2= 0.096$) was a less powerful determinant of percent fat mass than BMI (partial $r^2= 0.472$). These indicated that MAFA or TSFT could have lower sensitivity for detection of calorie-malnutrition than BMI. This also indicated that subcutaneous fat mass in upper limbs was not the most active portion of total fat mass. Two previous papers also support this finding. They showed that visceral adipose tissue has more lipolytic activity and higher expression of lipogenesis than subcutaneous adipose tissue [17, 18].

The results of multiple regression analyses and Mann Whitney U tests revealed that gender-based differences were seen in FFMI or percent fat mass. The results of Mann Whitney U tests revealed that gender-based differences were seen in MAMC and MAMA. This highlighted the importance of gender influence in the norms of derived estimates of BIA and MAMC of MHD patients [10, 12, 19]. From correlation study, MAC related to FFMI and percent fat mass. It indicated that MAC was a surrogate of combination of subcutaneous fat (triceps and biceps skinfold) and mid-arm muscle, along with bone and non-skeletal soft tissue.

Predialysis serum creatinine concentrations moderately correlated with indicators of muscle mass at the upper arm, such as MAMA, MAMC, and cMAMA, respectively. These results can be explained as follows. Creatinine is produced from the breakdown of muscle creatine phosphate during energy metabolism. The predialysis serum creatinine concentrations reflect the summation of the dietary ingestion of food rich in creatine and creatinine and endogenous creatinine production minus the urinary excretion, dialytic removal and extrarenal metabolism in the steady state [20]. In other words, predialysis serum creatinine values represented *muscle mass and dietary protein intake* in MHD patients with little or no residual renal function who are prescribed a constant dose of dialysis. Thus, if serum creatinine concentration is used as a parameter of nutrition in stable MHD patients, we have to be sure that hemodialysis doses are repeatedly adequate.

We found that serum albumin concentrations moderately related with cMAMA ($R= 0.393$) and MAMC ($R= 0.356$). This indicated that serum albumin levels were related to appendicular skeletal muscle mass of

upper arm in MHD patients. A previous paper also showed that lower serum albumin levels, even those above the cutoff of 3.8 g/dl, are related to a future loss of appendicular skeletal muscle mass in older subjects[21]. Another previous research also revealed that *serum albumin levels moderately associated with cross-sectional area of thigh muscle* derived from multi-slice spiral CT scanner (R= 0.45 in males; R= 0.48 in females) *in MHD patients* [22]. The mechanisms underlying the relationship between serum albumin levels and indicators of appendicular skeletal muscle mass may be explained as follows. 1. Modulation of cellular glutathione and iron binding antioxidant properties of albumin can protect against oxidative damage of skeletal muscle [23, 24]. 2. Activation of phosphatidylinositol-3-kinase pathway by albumin can stimulate muscle protein synthesis pathway [25, 26]. 3. Low-grade inflammatory conditions associated with MHD patients could simultaneously cause reduced albumin synthesis and muscle proteolysis [27]. 4. Changes of free amino acid availability can affect muscle protein synthesis and albumin synthesis [28, 29]. 5. Increased levels of free cortisol have been reported in hypoalbuminemic patients [30] and muscle wasting. The correlation coefficients between serum albumin concentrations and indicators of mid-arm muscle mass were lower than those between serum albumin concentrations and cross-sectional area of thigh *muscle* derived from multi-slice spiral CT scanner. This might easily be explained by the limitations of arm anthropometry. Hydration states would influence TSFT and MAC. The equations for calculating MAMC or cMAMA or MAMA were based on four assumptions: 1. Cross section of the mid-arm structures is a circular outline. 2. A concentric band of fat surrounds the muscle. 3. Mid-arm muscle compartment is circular. 4. The mid-arm structures contain a constant fraction of bone area.

The prevalence of protein wasting measured by MAMC (50%) appeared to be equivalent to that measured by serum albumin concentration (50%). Furthermore, MAMC can be used a leading parameter for cross sectional and longitudinal evaluation of nutrition because of the percentiles for MAMC of healthy Taiwanese population, the United States population of whites and the stable dialysis population were available.

Conclusion

Serum albumin *levels* may be insensitive to acute alterations in nutritional status, because albumin has a long half-life and hepatic synthetic reserve is very large. Besides, serum albumin *levels are* decreased both in the setting of systemic inflammation and in over-hydration states. Depletion of FFMI could be independently predicted by indicators of upper arm muscle (MAMC, cMAMA, MAMA) after adjustment for gender and BMI in MHD patients. Likewise, subcutaneous fat mass in upper limbs (MAFA or TSFT) was an independent predictor of percent fat mass after adjustment for BMI and gender in MHD patients. Upper arm anthropometry not only could be used independently to track relative nutritional changes in MHD patients, they also could be used in cross-sectional estimation of nutritional status regarding muscle mass and fat mass of MHD patients if reference values are available. The nutritional indexes of arm anthropometry and body composition by BIA can be used for longitudinal monitoring of nutritional status in MHD patients. Then nutritional intervention, precision medicine for nutrition management, aerobic and resistant exercise programs and anti-inflammatory and antioxidant nutritional supplements can be focused on patients with protein calorie wasting [31-34].

Because of the novel COVID-19 outbreak, we suggest that markers of bioimpedance and upper arm anthropometry had better not to be obtained nowadays to help fight the global pandemic of this virus. Variables of biochemical marker, such as albumin, serum creatinine are suitable to help us through hard times. In the conclusion section, we must emphasize this viewpoint.

Abbreviations

Asymp. Sig	asymptotic significance
BA-200	body composition analyzer -200
BCG method	bromcresol green method
BIA	bioelectrical impedance analysis
BMI	body mass index
BUN	blood urea nitrogen
cMAMA	corrected mid-arm muscle area
DBW	dry body weight
FFM	fat free mass
FFMI	height-normalized indices of fat-free mass
FM%	percent fat mass
IQR	interquartile range
LBM	lean body mass
MAC	mid-arm circumference
MAFA	mid-arm fat area
MAMA	mid-arm muscle area
MAMC	mid-arm muscle circumference
MHD	maintenance hemodialysis
SCr	serum creatinine
SD	standard deviation
SPSS	Statistical Product and Service Solutions
TSFT	triceps skinfold thickness
MAA	mid-arm area
WHO	World Health Organization

Declarations

Ethics approval and consent to participate: The department of teaching and research, the counterpart of ethical committee, of Taipei Municipal Zhongxiao Hospital approved this research study in 2003. The department of teaching and research of Taipei City Hospital also approved this research study in June, 2020 with the case number 10939. Institutional review board of Taipei City hospital approved this research with the case number TCHIRB-10907008-E.

Consent for publication: Not applicable.

Availability of data and material: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests: There are no competing interests related to this study.

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Author contributions: conceived and designed the experiments: Jenn-Yeu Wang; analyzed the data: Jenn-Yeu Wang; performed the measurements and contributed analysis tools: Miss Chen Shu- Chin; contributed to the writing of the manuscript: Jenn-Yeu Wang; Betau Hwang.

Additional Material: The appendix A includes box plots displaying gender-based differences of variables. Dummy variables were used for gender (male=1, female=0).

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Tables

Table 1. Basic characteristics of the study subjects

Parameters	Total Mean \pm SD	Female, No (%), 17 (53) Median (IQR)	Male, No (%), 15 (47) Median (IQR)	Asymp Sig.(2- tailed)
Total protein, g/dL	6.68 \pm 0.54	6.60(6.35-6.95)	6.80(6.60-7.10)	0.264
Albumin, g/dL	3.69 \pm 0.60	3.80(2.85-4.05)	3.70(3.40-4.40)	0.325
BUN, mg/dL	69.47 \pm 16.96	72.00(58.50-85.50)	61.00(52.00-81.00)	0.242
Creatinine, mg/dL	9.85 \pm 2.67	8.80(7.00-10.10)	11.40(9.70-12.30)	0.026
Cholesterol, mg/dL	166.09 \pm 50.91	163.00(127.00-212.50)	153.00(123.00-198.00)	0.664
Triglyceride, mg/dL	176.63 \pm 109.77	148.00(78.50-245.50)	151.00(106.00-265.00)	0.835
Age, years	61.97 \pm 13.44	62.00(50.50-68.00)	65.00(58.00-76.00)	0.316
Height, cm	161.82 \pm 7.58	156.00(152.75-160.50)	168.00(164.00-172.00)	<0.001
DBW, kg	57.57 \pm 9.79	51.70(48.50-56.65)	61.00(55.8-68.8)	0.002
BMI, kg/m ²	21.87 \pm 2.87	21.30(19.10-23.60)	22.10(20.10-23.10)	0.428
TSFT, mm	21.55 \pm 8.95	23.00(20.50-29.15)	16.50(12.00-24.3)	0.070
MAC, cm	26.02 \pm 2.88	26.00(23.45-27.50)	27.00(24.00-28.50)	0.233
MAMC, cm	19.25 \pm 2.75	18.41(16.12-19.45)	20.37(18.82-22.55)	0.003
MAFA, mm ²	2444.75 \pm 1030.23	2620.74(2167.35-3221.64)	1901.20(1355.87-2938.47)	0.180
MAMA, mm ²	3009.16 \pm 866.64	2697.30(2069.32-3012.24)	3303.57(2819.70-4047.15)	0.003
cMAMA, mm ²	2206.04 \pm 772.66	2047.30(1419.32-2362.24)	2303.57(1819.70-3047.15)	0.073
FM, kg	13.25 \pm 6.20	12.10(10.30-17.15)	12.00(9.00-18.00)	0.664
Percent fat mass, %	21.75 \pm 8.92	24.40(19.50-33.50)	19.20(10.60-23.40)	0.018
LBM, kg	44.87 \pm 8.34	40.30(35.90-41.95)	52.20(46.8-54.80)	<0.001
FFMI, kg/m ²	16.99 \pm 1.89	15.78(14.90-16.41)	17.84(16.95-19.33)	<0.001
TBW, kg	35.92 \pm 6.65	32.00(28.70-33.55)	41.50(37.60-43.90)	<0.001
Hemoglobin	9.41 \pm 1.20	9.40(8.65-10.00)	9.90(8.60-10.20)	0.57

Data were presented as mean \pm SD (standard deviation) or median (IQR; interquartile range). Asp. Sig. (Asymptotic significance) of difference between female and male (non-parametric, Mann-Whitney U test). Abbreviations: TSFT, triceps skinfold thickness; MAC, mid-arm circumference; MAMC, mid-arm muscle circumference; MAFA, mid-arm fat area; cMAMA, corrected mid-arm muscle area; MAMA, mid-arm muscle area; BMI, body mass index; DBW, dry body weight; LBM, lean body mass; FM, fat mass; FFMI, height – normalized indices of fat-free mass.

Table 2a

	MAC	MAMC	cMAMA	MAMA	TSFT	MAFA	gender	BMI
FFMI	0.446*	0.718***	0.653***	0.727***	-0.246	-0.099	0.659***	0.515**
%FM	0.498**	-0.196	-0.110	-0.197	0.703***	0.718***	-0.466**	0.627***

*P < 0.05, **p < 0.01, ***P < 0.001, by Pearson correlation. Abbreviations: TSFT, triceps skinfold thickness; MAC, mid-arm circumference; MAMC, mid-arm muscle circumference; MAFA, mid-arm fat area; cMAMA, corrected mid-arm muscle area; MAMA, mid-arm muscle area; BMI, body mass index; %FM, percent fat mass; FFMI, height- normalized indices of fat – free mass

Table 2b

	MAC	MAMC	cMAMA	MAMA	TSFT	MAFA
TP	0.356*	0.243	0.275	0.248	0.126	0.199
albumin	0.506**	0.356*	0.393*	0.378*	0.170	0.241
BUN	0.017	0.031	0.067	0.034	-0.014	-0.021
creatinine	0.562**	0.576**	0.560**	0.575**	0.011	0.126
cholesterol	0.207	-0.081	-0.082	-0.097	0.292	0.301
triglyceride	0.292	-0.085	-0.068	-0.089	0.384*	0.390*

*P < 0.05, **p < 0.01, by Pearson correlation. Abbreviations: triceps skinfold thickness (TSFT); MAC, mid-arm circumference; MAMC, mid-arm muscle circumference; MAFA, mid-arm fat area; cMAMA, corrected mid-arm muscle area; MAMA, mid-arm muscle area.

Table 3a – 3d. Multiple regression analyses of variables affecting height- normalized indices of fat – free mass.

Table 3a

Independent variables	Standardized β coefficient	partial r^2	P value
gender	0.658	0.434	<0.001
BMI	0.500	0.194	0.011
MAC	-0.004	0.003	NS
age	-0.182	0.020	NS
albumin	-0.147	0.014	NS

Table 3b

Independent variables	Standardized β coefficient	partial r^2	P value
gender	0.478	0.434	0.001
BMI	0.383	0.194	0.003
MAMC	0.364	0.075	0.012
Age	-0.136	0.008	NS
albumin	-0.190	0.028	NS

Table 3c

Independent variables	Standardized β coefficient	partial r^2	P value
gender	0.468	0.434	0.001
BMI	0.377	0.194	0.003
MAMA	0.383	0.080	0.009
Age	-0.127	0.006	NS
albumin	-0.199	0.030	NS

Table 3d

Independent variables	Standardized β coefficient	partial r^2	P value
gender	0.542	0.434	<0.001
BMI	0.383	0.194	0.003
cMAMA	0.343	0.073	0.011
age	-0.134	0.007	NS
albumin	-0.209	0.033	NS

Dummy variables were used for gender (male=1, female=0). The standardized β coefficient of the variable was given in the left column. The independent statistical significance of the variable was listed in the right column. The partial r^2 of the variable was shown in the central column. Abbreviations: NS, not significant; BMI, body mass index; MAC, mid-arm circumference; MAMC, mid- arm muscle circumference; MAMA, mid-arm muscle area; cMAMA, corrected mid-arm muscle area.

Table 4a-4c Multiple regression analyses of variables affecting percent fat mass.

Table 4a

Independent variables	Standardized β coefficient	partial r^2	P value
gender	-0.567	0.217	<0.001
BMI	0.539	0.427	0.003
MAC	0.162	0.017	NS
age	0.083	0.012	NS
TG	0.129	0.014	NS

Table 4b

Independent variables	Standardized β coefficient	partial r^2	P value
gender	-0.430	0.217	<0.001
BMI	0.531	0.472	<0.001
TSFT	0.331	0.096	0.007
age	0.046	0.003	NS
TG	0.068	0.004	NS

Table 4c

Independent variables	Standardized β coefficient	partial r^2	P value
gender	-0.458	0.217	<0.001
BMI	0.487	0.472	<0.001
MAFA	0.334	0.089	0.010
age	0.048	0.003	NS
TG	0.071	0.004	NS

Dummy variables were used for gender (male=1, female=0). The standardized β coefficient of the variable was given in the left column. The independent statistical significance of the variable was listed in the right column. The partial r^2 of the variable was shown in the central column. Abbreviations: NS, not significant; BMI, body mass index; MAC, mid-arm circumference; TSFT, triceps skinfold thickness; MAFA, mid-arm fat area; TG, triglyceride.

Figures

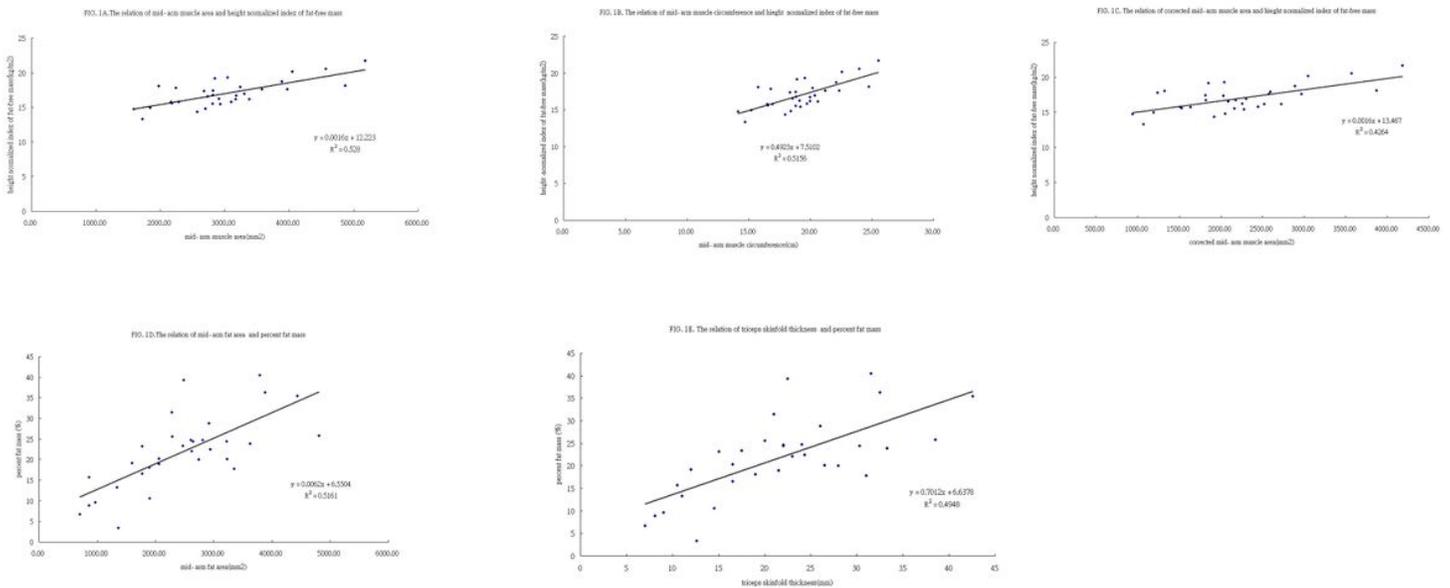


Figure 1

A. Relationship between bioelectrical impedance analysis (BIA) determined height normalized indices of fat –free mass (FFMI) and upper arm anthropometry determined mid- arm muscle area B. Relationship between bioelectrical impedance analysis (BIA) determined height normalized indices of fat –free mass (FFMI) and upper arm anthropometry determined mid-arm muscle circumference C. Relationship between bioelectrical

impedance analysis (BIA) determined height normalized indices of fat – free mass (FFMI) and upper arm anthropometry determined corrected mid-arm muscle area D. Relationship between bioelectrical impedance analysis (BIA) determined percent fat mass and upper arm anthropometry determined mid-arm fat area E. Relationship between bioelectrical impedance analysis (BIA) determined percent fat mass and upper arm anthropometry determined triceps skinfold thickness

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