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Body composition measurement in obese patients with and without type 2 diabetes: comparison of methods

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Background. Previous studies have compared body composition (BC) assessment methods in obese patients, however there is lack of literature on the comparison of bedside BC methods in obese diabetic subjects, particularly with respect to regional body fat (BF) distribution.

The aim of this study was: to estimate the differences in fat mass (FM) using bioelectrical impedance (BIA), skinfold thickness (SFT) and body mass index (BMI) in comparison to the reference method of deuterium oxide (D_2O) dilution in obese patients with and without type 2 diabetes (DM); to relate the differences in percentage of fat mass (%FM) to the regional body fat (BF) distribution.

Materials and methods. BC was estimated using anthropometry, D_2O, BIA, SFT, and BMI was used to calculate fat content in 94 obese patients, of whom 53 participants had type 2 DM (obese DM).

Results. BIA and SFT yielded 5.2% and 6.1% lower ($p < 0.001$) results of %FM, respectively, in obese without DM, and 3.9% ($p = 0.01$) and 2.8% ($p = 0.037$) lower results in obese DM group, accordingly, compared to D_2O dilution, while %FM calculated using BMI was higher by 3.2% ($p = 0.045$) in obese DM group. The difference estimated by BIA was constant for all the obesity classes, whereas for SFT increased in parallel with body weight. Fat in legs, arms, trunk area and waist to hip ratio were all important determinants for the difference in %FM between D_2O dilution and bedside methods.

Conclusions. The BIA and SFT underestimated FM in obese with and without DM, while BMI overestimated FM in obese DM group in comparison to D_2O. The differences in regional body fat distribution were significant predictor variables, influencing the accuracy of the %FM estimated in all the patient groups.

Key words: body composition, deuterium dilution, obesity, diabetes

INTRODUCTION

The prevalence of obesity is increasing among youths and adults throughout the world. Excessive body fat (BF) is associated with health problems, particularly, with type 2 diabetes (1). Regional distribution of adipose tissue is important as the excess of abdominal fat mass (FM) increases the risk of diabetes at any body mass index (BMI) level (2).

Body composition (BC) *in vivo* may be accurately estimated using laboratory techniques such as underwater weighing (UWW), air displacement plethysmography (e. g. Bod Pod), dual X-ray absorptiometry (DEXA), tracer dilution (deuterium oxide (D_2O), tritium or ^{18}O dilution) or radioactive potassium counting (3), by both a basic two-compartment (2C) and multi-compartment models. The prevalent 2C model system of BC assessment is based on the assumption of constant density of human body FM and fat free mass (FFM). In addition, the finding that water occupies a relatively fixed fraction of the FFM (4) has stimulated the determination of total body water (TBW) as an index of human BC using dilution techniques. Accurate regional estimation of body fat compartments requires imaging techniques such as magnetic resonance imaging (MRI) or computed tomography (CT) (5). However, the use of the above techniques in daily clinical practice is limited, mainly because these methods are expensive and/or use radiation. However, bioelectrical impedance analysis (BIA) and anthropometry such as skinfold thickness (SFT), body weight (BW), height, body circumferences are readily available, inexpensive and are therefore commonly used techniques in the clinical setting. Multi-compartment models would be preferred under these circumstances, but these are not always viable. Thus, comparison of the indirect methods such as SFT, BIA and BMI against a reference technique such as deuterium oxide dilution can be helpful in choosing an adequate BC measuring method for routine clinical practice. Many studies have compared these methods in patient groups with cancer (6), HIV infection (7) and pregnancy (8). Studies in diabetic patients have reported on the relation of regional fat distribu-

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tion and metabolic abnormalities (9) or have access to visceral abdominal fat in relation to diabetes using imaging techniques (10) but there is lack of literature on the comparison of bedside anthropometric methods in diabetic subjects, particularly on regional BF distribution differences. One may anticipate that with the development of altered metabolic state, the techniques may have differing sensitivities in this patient group.

The aims of this study were, therefore: 1) to compare the indirect bedside methods of BC with the deuterium oxide dilution in obese patient group and within each of 2 subgroups – obese with (obese DM) and without (obese without DM) type 2 diabetes using a two-compartment BC model; 2) to determine whether the regional body fat distribution is related to the difference in fat mass (FM) estimated using BMI, SFT and BIA from the criterion method.

RESEARCH DESIGN AND METHODS

Ninety-four obese Caucasians (54 females and 40 males) were recruited from Woolmanhill Obesity and Diabetic Clinic in Aberdeen, Scotland, United Kingdom (UK). Fifty-three participants had type 2 diabetes (25 females and 28 males). Written, informed consent was obtained from all the subjects. The study was approved by the Grampian Research Ethics Committee.

Inclusion criteria were: males and females between the ages of 18 to 75 years, and BMI > 30 kg/m^2. Patients with any severe cardiac problems, malignant tumours, psychiatric disorders, abnormal thyroid function or taking L-thyroxin, beta-blockers and/or diuretics were excluded from the study. All tests were undertaken in the morning at the Clinical Research Unit at Foresterhill Hospital, under standardized conditions, using a standard operating procedure. Subjects arrived after an overnight rest and fast of at least 12 hours. They were asked to avoid vigorous physical activity, not to consume coffee or tea or to smoke prior to attending in the Unit.

MEASUREMENT OF BODY COMPOSITION

Height was measured at the nearest 0.5 cm (Holtain Ltd, Crymych, Dyfed, Wales) and body weight (BW) to the nearest 0.1 kg by digital weighing scales (TANITA Corporation, Tokyo, Japan). Percentage of fat mass (%FM) and regional body fat distribution in arms, legs and trunk (upper body) area was estimated using the single frequency 50 kHz current eight-electrode model bioelectrical impedance analyzer (BC-418 MA, TANITA Corporation, Tokyo, Japan). The ratio of %FM in trunk and peripheral area was calculated as follows: trunk / peripheral = %FM in trunk area / (%FM arms + %FM legs). All the measurements were taken with empty bladder, barefoot, without clothing and wearing a hospital gown of known weight, which then was subtracted from the measured BW.

BMI was calculated as body weight in kilograms divided by the square of the height in meters. Fat mass % was calculated from BMI using the equation of Deurenberg (11):

Equation 1: %BF = (1.2 × BMI) + (0.23 × age) – (10.8 × sex) – 5.4, where 1.2 and 0.23 are coefficients; males = 1, females = 0.

SFT were measured 3 times (to the nearest 0.1 mm) with a Harpenden calliper (British Indicators, Ltd, London) at the triceps, biceps, subscapular, and suprailiac sites on the right side of the body as described by the International Society for the Advancement of Kinanthropometry (ISAK) (12). The results of 3 measurements were used to calculate the average. The equations of Durnin and Womersley were used to predict body density (kg/L) (13), and the Siri equation was used to calculate %FM (14). The guidelines of the ISAK were followed for inter-subject repeatability, which is no more than 7.5% for a skinfold measurement (15). In practice, within the Rowett Research Institute Human Nutrition Unit Lab, the repeatability of measurement on the same subject by the same measurer, on different days, is –1.03 mm, which equates to a 0.24% difference in body fat estimation. This was calculated from the data on 17 obese males, repeated three days apart, whilst fed to energy balance, as an average for the sum of the four sites.

Waist and gluteal (hip) circumferences were measured with the subject standing in relaxed position with arms folded across the thorax, feet being together and gluteal muscle relaxed as described in ISAK. The waist to hip ratio (WHR) was then calculated from the duplicate measurements.

MEASUREMENT OF TOTAL BODY WATER (TBW)

Total body water (TBW-kg) was measured by deuterium dilution as described by Speakman (16). A two-point plateau method was used to obtain pre-dose and equilibration samples. Baseline urine analyses were used to determine the background deuterium concentration and to empty the bladder prior to dosing. A dose of ~0.1 mg deuterium / kg body weight (99.9% deuterium oxide), adjusted to about 100 ml with Aberdeen tap water, was given to drink through a straw. Another 100 ml of tap water were used as a rinse and then consumed to ensure complete ingestion of the tracer. Subjects were asked to void 3.5 hours after the deuterium dose and then again, at 4 hours after deuterium dose equilibrium (plateau) samples of urine were obtained. Urine samples were collected in glass airtight containers and stored in –80 °C until analysis.

The deuterium concentrations in the urine samples were determined on an isotope-ratio mass spectrometer (IsoPrime, Micromass UK Ltd) which was calibrated against Vienna Standard Mean Ocean Water. Each sample and dose aliquot was analysed in duplicate to a precision of 0.3–0.4 ppm.

The TBW was calculated as described elsewhere (17), using a 4% correction factor for the exchange of D_2O with labile H of protein and other body constituents. Fat free mass (FFM) was calculated on the assumption that water occupies 73.2% of FFM mass (18). FM was determined as the difference between BW and FFM:

Equation 2: FM kg = BW (kg) – FFM (kg). %FM was computed as [(BW – FFM) / BW] × 100.

STATISTICAL ANALYSIS

A two-sample paired Student's test was used to compare the means from two groups. Analysis of variance (ANOVA) was used to compare means from three samples (obesity classes). Pearson's correlation was used to assess the strength of the relationship between the methods and Bland and Altman plot

Table 1. **Clinical characteristics of all obese patients (n = 94), grouped into three obesity classes and sorted according to diabetes status**

Variable	All patients	Obesity class* I	II	III	Diabetes status Obese without DM	Obese DM	p value**
N (Female/male)	94 (54/40)	32 (19/13)	31 (16/19)	31 (19/12)	41 (29/12)	53 (25/28)	
(with DM/ without DM)	(53/41)	(20/12)	(17/14)	(16/15)			
Age (year)	49.7 (47.2–52.3)	52.6 (48.2–56.9)	49.9 (45.1–54.6)	46.6 (42.2–50.9)	42.4 (39.2–45.6)	55.4 (52.3–58.4)	<0.001
BW (kg)	108.5 (104.2–112.7)	91.5 (87.7–95.3)	107.4 (102.2–112.5)	127.1 (120.1–134.2)	109.2 (102.2–116.2)	107.9 (102.4–113.5)	0.780
BMI (kg/m^2)	38.4 (7.3–39.6)	33.0 (32.5–33.4)	37.4 (36.9–38.0)	45.1 (43.4–6.9)	39.1 (37.2–41.0)	37.9 (36.3–9.5)	0.312
Height (cm)	164.6 (165.7–169.5)	166.3 (163.3–169.4)	169.0 (165.2–172.9)	167.4 (164.2–170.5)	166.3 (163.3–169.4)	168.5 (166.1–170.9)	0.261
%FM (D_2O)	45.8 (44.4–47.3)	42.3 (39.6–45.0)	44.5 (42.1–47.0)	50.8 (49.1–52.5)	48.4 (46.5–50.2)	43.9 (41.8–46.0)	0.003
FM kg (D_2O)	49.0 (47.2–52.8)	38.4 (36.0–40.8)	47.5 (44.6–50.4)	64.5 (60.5–68.6)	52.9 (48.7–57.1)	47.7 (43.9–51.6)	0.072
%FM (BIA)	41.4 (39.9–42.9)	37.8 (35.3–40.3)	39.9 (37.2–42.6)	46.6 (44.7–48.5)	43.2 (41.1–45.4)	40.0 (37.8–42.1)	0.036
%FM (SFT)	41.6 (40.6–42.7)	39.5 (37.5–41.5)	41.0 (39.1–42.8)	44.5 (43.1–45.8)	42.3 (40.9–43.8)	41.1 (39.5–42.7)	0.275
%FM (BMI)	47.6 (45.1–50.1)	41.8 (40.3–43.2)	45.8 (43.7–47.9)	55.3 (52.6–58.0)	48.2 (46.3–50.1)	47.1 (45.9–48.3)	0.301
Fat arms %	43.2 (41.5–46.2)	38.0 (35.1–42.3)	41.4 (36.1–44.4)	52.4 (48.9–55.0)	46.5 (43.1–49.9)	41.8 (38.6–45.1)	0.049
Fat legs %	40.9 (39.6–43.6)	39.1 (36.1–43.3)	39.7 (35.1–42.7)	46.0 (42.9–48.6)	44.3 (41.7–46.9)	39.5 (36.6–42.3)	0.017
Fat trunk %	39.7 (39.1–41.7)	36.7 (35.0–39.0)	39.5 (36.6–41.0)	45.3 (43.6–46.7)	41.5 (39.6–43.4)	39.6 (37.8–41.4)	0.155
Trunk/peripheral	0.48 (0.47–0.49)	0.49 (0.46-0–52)	0.51 (0.48–0.55)	0.47 (0.45–0.50)	0.47 (0.45–0.49)	0.51 (0.48–0.53)	0.026
Waist (cm)	119.1 (116.2–121.8)	108.4 (105.6–111.2)	116.8 (113.3–120.2)	132.3 (128.2–136.5)	117.2 (113.0–121.4)	120.5 (116.6–124.3)	0.257
Hip (cm)	120.5 (119.9–125.7)	115.5 (111.1–119.8)	120.1 (117.0–123.2)	137.3 (133.2–141.3)	125.0 (121.0–129.1)	121.1 (117.1–125.2)	0.183
WHR	0.97 (0.96–0.99)	0.98 (0.94–1.01)	0.98 (0.94–1.01)	0.97 (0.94–0.99)	0.94 (0.91–0.97)	1.0 (0.98–1.01)	0.002
WHtR	0.70 (0.69–0.72)	0.65 (0.63–0.66)	0.69 (0.67–0.70)	0.79 (0.77–0.81)	0.70 (0.68–0.72)	0.72 (0.71–0.73)	0.503

Notes. Data are means with 95% confidence interval (95% CI).

* ANOVA analysis showed significant difference for all variables ($p < 0.001$), $p = 0.007$ for fat legs % and no significant difference in height, trunk / peripheral and WHR, comparing different obesity classes.

** Comparison of obese without DM and obese DM groups.

Abbreviations: N, number of patients; BW, body weight; BMI, body mass index; FM, fat mass; D_2O, deuterium dilution; BIA, bioelectrical impedance; SFT, skinfold thickness; WHR, waist to hip ratio; WHtR, waist to height ratio.

Table 2. **The difference in %FM estimated by BMI, BIA and SFT vs. %FM estimated by D_2O dilution in different obesity class groups**

Obesity class	BMI vs. D_2O	p value	BIA vs. D_2O	p value	SFT vs. D_2O	p value
I (n = 32)	–0.5%	0.07	–4.7%	0.01	–2.8%	0.09
II (n = 31)	+1.2%	0.46	–4.6%	0.01	–3.5%	0.02
III (n = 31)	+4.5%	0.002	–4.2%	<0.001	–6.3%	<0.001

Abbreviations: n, number of patients; BMI, body mass index; BIA, bioelectrical impedance; SFT, skinfold thickness; D_2O, deuterium dilution.

Table 3. **Mean differences and the limits of agreement for body fat mass (%) in all obese patients (n = 94)**

Methods	Mean difference ± SD (95% limits of agreement)
BMI vs. D_2O	1.73 ± 5.56 (–9.17 to 12.63)
SFT vs. D_2O	–4.21 ± 5.16 (–14.32 to 5.9)
BIA vs. D_2O	–4.46 ± 3.92 (–8.38 to –0.7)

Abbreviations: BMI, body mass index; BIA, bioelectrical impedance; SFT, skinfold thickness; D2O, deuterium dilution.

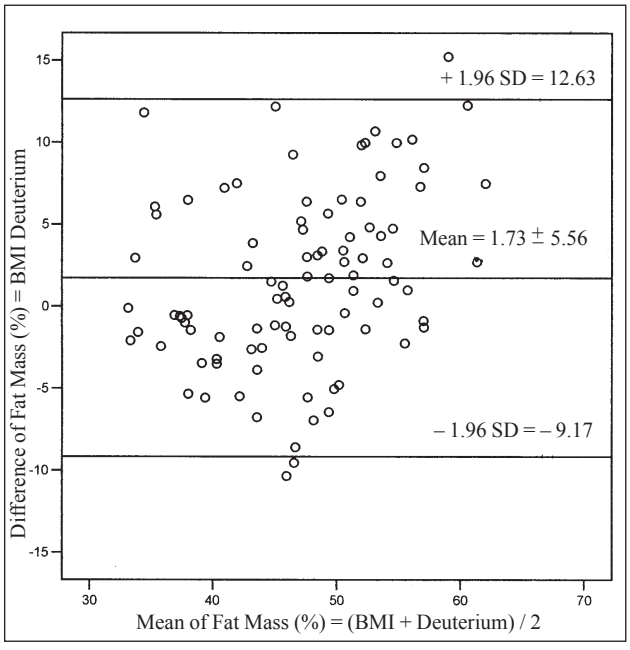

Fig. 1. Bland and Altman plot analysis to evaluate the agreement between the methods of BMI and D_2O for the assessment of body fat mass (%) in 94 obese subjects. The differences of FM% are plotted against the mean of %FM obtained by two methods

analysis (19) to evaluate the agreement of the BMI, SFT and BIA with D2O dilution. Several regression models were performed by multivariate regression analysis using the difference in %FM as the dependent variable and regional body fat distribution data as independent variables. Statistical analysis was performed with the GenStat statistical program (8th edition for Windows, Rothampstead Experimental Station, Harpenden, UK).

RESULTS

Table 1 summarizes the subject characteristics. Firstly, patients were grouped into three obesity class groups based on BMI, as recommended by the World Health Organization (WHO) (20): class I obesity with BMI 30.0–34.9 kg/m^2, class II obesity with BMI 35.0–39.9 kg/m^2, class III obesity with BMI > 40 kg/m^2; secondly, patients were grouped into two groups regarding diabetes status: forty one obese and fifty three obese subjects with type 2 diabetes.

Estimation of body fat percentage – effect of obesity

Data analysis in all the patients (n = 94) between the obesity classes showed that %FM was underestimated up to 4.7% (p = 0.01) using BIA in all the classes of obesity and up to 6.3% (p < 0.001) using SFT in classes II and III of obesity compared to D_2O, while BMI overestimated %FM by 4.5% (p = 0.002) only in class III of obesity as shown in Table 2. These data indicate that mathematical calculation of %FM using BMI was accurate for classes I and II of obesity (BMI up to 39.9 kg/m^2). The difference in %FM increased with BMI for all methods used (p < 0.01), except for BIA which indicated no difference in %FM compared to D2O dilution for more obese patients in class III.

Percentage of fat mass estimated by BIA, BMI and SFT correlated significantly with %FM (D_2O) (r = 0.82; 0.75 and 0.71, respectively, p < 0.001). However, there was no agreement between deuterium dilution and BMI, SFT and BIA methods, as illustrated in Table 3. Figure represents the Bland and Altman plot analysis to evaluate the agreement between the BMI and D_2O method for the assessment of body fat mass (%). The Bland and Altman plot analyses for SFT and BIA were similar to the represented one.

Estimation of body fat percentage – effect of diabetic status

The bedside BC methods were also compared in obese type 2 diabetes subjects and the obese without diabetes (Table 1), as we hypothesized that differences in regional body fat distribution could possibly influence the accuracy of BC assessment methods. Analysis of %FM in arms, legs, trunk area and WHR revealed different adipose tissue distribution with higher % fat in arms (p = 0.049) and legs (p = 0.019) in the obese group, and higher WHR (p = 0.002) in the obese DM group. Thus, obese patients with type 2 diabetes had more central BF distribution compared to the healthy obese. The calculation of %FM distributed in trunk area to %FM distributed in arms and legs (peripheral area) indicated 0.51 ± 0.09 ratio in the diabetic group in comparison to 0.47 ± 0.07 within the obese group (p = 0.026), further supporting the hypothesis about a more central distribution of adipose tissue in the diabetic group.

The difference in %FM estimated by various techniques demonstrated that BIA and SFT underestimated %FM in both groups while BMI overestimated %FM only in the obese patients with type 2 diabetes compared to deuterium dilution (Table 4).

Table 4. **The difference in %FM estimated by BMI, BIA and SFT vs. %FM estimated by D_2O dilution in obese without DM (n = 41) and obese DM (n = 53) subjects**

	BMI vs. D_2O	p value	BIA vs. D_2O	p value	SFT vs. D_2O	p value
Obese without DM	–0.2%	0.080	–5.2%	<0.001	–6.1%	<0.001
Obese DM	+3.2%	0.045	–3.9%	0.01	–2.8%	0.037

Table 5. **Coefficients and significance of variables in the multiple regression equations predicting the difference in %FM estimated by BMI, SFT, BIA in obese patients group (n = 94) from the deuterium oxide dilution**

Variable	Coefficient	SE	t	p value	R^2 adjusted
		Difference in %FM (BMI vs. D_2O)			0.16
Constant	9.0	4.1	2.2	0.03	
Fat legs %	–4.7	0.1	–3.3	0.001	
Fat arms %	0.7	0.2	4.4	<0.001	
Fat trunk %	–0.4	0.2	–2.8	0.006	
		Difference in %FM (SFT vs. D_2O)			0.19
Constant	10.6	3.1	3.4	0.001	
Fat trunk %	–0.4	0.1	–4.8	<0.001	
		Difference in %FM (BIA vs. D_2O)			0.18
Constant	–27.6	5.9	–4.7	<0.001	
Fat legs %	0.2	0.04	4.7	<0.001	
WHR	14.8	4.8	3.1	0.003	

Abbreviations: BMI, body mass index; D_2O, deuterium dilution; BIA, bioelectrical impedance; SFT, skinfold thickness; WHR, waist to hip ratio; FM, fat mass.

Table 6. **The difference in %FM estimated by BMI, BIA and SFT vs. %FM estimated by D_2O dilution in in male (n = 40) and female (n = 54) groups**

	BMI vs. D_2O	p value	BIA vs. D_2O	p value	SFT vs. D_2O	p value
Male (n = 40)	+1.4	0.412	–5.9	<0.001	–3.6	0.011
Female (n = 54)	+1.9	0.063	–3.4	<0.001	–4.7	<0.001

Abbreviations: BMI, body mass index; D_2O, deuterium dilution; BIA, bioelectrical impedance; SFT, skinfold thickness; FM, fat mass.

We performed a multivariate regression analysis to test the hypothesis that the variables of regional BF distribution are possible predictors of the estimated difference in %FM from the criterion method of D_2O dilution. Patients age, gender, BW or BMI were not included into the model, as %FM predictions used in BMI, SFT or BIA already comprise these variables. Table 5 presents significant regression models estimated for all the methods. It demonstrats that the specific distribution of adipose tissue, particularly percentage of fat in arms, legs, trunk area and WHR ratio, were all significant variables influencing the estimated difference in %FM by BMI, SFT and BIA methods, in comparison to the criterion.

We also analyzed male and female subjects separately to see if there are any effects due to gender on the technique comparisons, but similar tendency as detected within the different obesity classes or diabetes groups was observed, with SFT and BIA underestimating and BMI estimation being the most accurate method in comparison to the deuterium oxide dilution technique. Table 6 presents the difference in %FM estimated by BMI, BIA and SFT compared to %FM estimated by D_2O dilution both in males and females. The groups did not differ in age and BMI, but females were shorter, lighter and had significantly higher total FM, percentage of fat mass distributed in legs, arms and trunk area and significantly lower WC and WHR.

DISCUSSION

The principal finding of this study was that %FM cannot be estimated accurately from SFT, BIA or BMI in either obese subjects or obese patients with type 2 diabetes. Errors of up to 5.2% can be introduced in the estimation of percentage of FM, in comparison to measurements made with deuterium dilution. These differences in %FM are related to the specific distribution of adipose tissue, which is particularly important in obese type 2 DM patients and distinguish them from obese subjects without diabetes. Thus, not only BMI but also the type of body fat distribution may lead to choose different BC assessment methods in daily clinical practice.

UWW (generally considered as the "golden standard") or multi-compartment models for assessing BC are more accurate, however we chose D_2O as a reference method as relatively simple and safe to use in the clinical setting when more sophisticated techniques are not available. There is good agreement between the deuterium dilution technique and UWW, with an estimated bias of 1.5%, explained by a higher estimate of FM% by the deuterium dilution technique (21). One concern with the use of D_2O dilution as the reference method is whether the standard FFM hydration coefficient of 0.732 is accurate for the obese population in question. Although this assumed value may be accurate

for many individuals and populations, deviations from this constant are recognized under the influence of biological factors such as age, adiposity or the phase of female menstrual cycle and may all contribute directly to the observed variability in FFM hydration (22). For example, studies of very old adults (–84 years old) showed a significantly higher TBW : FFM than that observed in young adults (23). However, other investigators did not observe any age-related change in FFM hydration in male (24) and female (25) groups. Although these discrepant results may be caused by population differences or the measurement methods applied, it is clear that the variability in FFM hydration may lead to the estimation errors of FFM and FM. In the present study, standard procedures were used to reduce potential methodological errors, however, the lack of information about the menstrual cycle stage in fertile female participants (n = 20, or 21% of all the subjects) could influence the individual variation in hydration and, therefore, contribute to differences between techniques. Insulin therapy is known to influence hydration (26), there were 9% of obese type 2 diabetes patients treated with this therapy. All these limitations are valid in discussing the use of deuterium dilution as the reference method and the use BIA for estimation of TBW.

The BIA method in obese subjects may both underestimate %BF and overestimate %BF, depending on the equation chosen. This mostly relates to the use of the equation in a group of similar subjects as the equation was developed. The equation for the TANITA machine utilised in the current study is not published. Several investigators have reported that BIA underestimates FM in populations of obese subjects (27). These studies have indicated that the body geometry of these subjects, or rather their regional body composition, is a helpful predictor of fat mass (28). The eight electrode system, used in the TANITA BC-418 MA analyzer, has been validated against DEXA in forty subjects ranging in age from six to sixty-four years. The analysis of the percentage of segmental and total body fat demonstrated by this system is in agreement with the reference technique ($R = 0.95$, $p < 0.001$ for lean soft tissue and $R = 0.87$, $p < 0.001$ for % of total body fat) (29). A cross-sectional study of 136 obese women of 48.1 ± 7.7 years of age concluded that TANITA BC-418 MA analyzer underestimated both total and trunkal fatness, compared with the DEXA (30). The current study confirmed that BIA statistically significantly underestimates %FM in comparison to D_2O dilution in obese subjects. Although this was shown within both the whole population and the different BMI groups, the difference in %FM was less in more obese subjects and in those with central body fat distribution (obese DM group). These results may be explained by the geometric proportions of obese individuals: a greater proportion of body mass and body water is accounted for by the trunk in relation to the extremities; the trunk, however, contributes a relatively minor amount to total body impedance. Thus, regional BF distribution could influence the difference in %FM estimated by BIA and D_2O.

Regression analysis confirmed that WHR and % fat in legs were significant predictors of the difference in %FM. It is also important to consider that these results might be related to the limitations of BIA analyzer, which operates at a single frequency of 50 kHz. Although this frequency represents the mean characteristic of muscle tissue, it may vary widely from 30 to more than 100 kHz among individuals (31), thus, multi frequency BIA assessing segmental body fat distribution may be more accurate in estimating FM. Despite the data about regional body fat distribution (arms, legs, trunk area), single frequency BIA does not give any idea about intra abdominal or subcutaneous body fat, which is important in clinical practice for evaluating the risk of the development of type 2 diabetes and cardiovascular disease. Thus, multi frequency BIA would be advantageous in this respect. A high correlation between %FM (BIA) and %FM (D_2O) confirms the single frequency BIA to be useful in assessing body composition in different BMI groups within clinical routine. It is appropriate for a quick assessment, where moderate inaccuracy is acceptable. However, D_2O should be considered as the method of choice, since accuracy gains special importance for research purposes.

Previous analyses have shown that the precision of SFT measurements to within 5% can be attained by a properly trained and experienced individual (32). This error can increase if skinfold thickness either gets very large (>15 mm) or small (<5 mm). Within the current study, the equations used estimated accurate mean values for %BF in class I obesity group (difference with %FM (D_2O) 2.8%), but there was a tendency to underestimate body fatness at higher levels of BMI. The limitation of SFT for estimation of %FM in this study might be that BMI varied from 30 to 57.5 kg/m^2 in the group, and the skinfold thickness was very large, increasing the possibility of an error. In the regression analysis, %fat in the trunk area was a significant predictor of the estimated difference in %FM, confirming a possible technical error with an increasing amount of fat in this area. This may relate to practical problems of raising a skinfold at this site in morbidly obese. However, the correlation of %FM (SFT) with %FM (D_2O) was statistically significant, and the difference in %FM was least in classes I and II obesity in comparison to D_2O dilution. Thus, these data suggest that the SFT method could be used in clinical routine for body composition estimation in obese subjects with BMI up to 35 kg/m^2. However, additional BC methods are recommended in more morbid obesity.

BMI is one of the most commonly used measurements at a population level as a proxy for adiposity. However, it is recognized that BMI is only a surrogate measure of adiposity and may not always be accurate to either identify obesity or predict body composition, with the suggestion that BMI-based measurements of body fat may be more limited, particularly in subjects with a BMI below 30 (33). Similarly, the current study revealed strong correlation between %FM (BMI) and %FM (D_2O), confirming previous results (34), with an overestimation of %FM in class II obesity by 4.5% and by 3.2% in the obese DM group, respectively. Few studies have examined the usefulness of BMI in morbidly obese subjects, however, it is likely that BMI-based estimates of body fat would be less accurate at the extreme states of body mass. Regression analysis revealed that %fat in the arms, legs and trunk area were significant predictors of the difference in %FM that could explain the discrepancy between these groups. Thus, BMI continues to serve well for estimation of %FM in up to moderate (class I) obese subjects, however, bias increases with BMI and with more centrally distributed body fat. More work is required in this area. BMI will still have limitations in measur-

ing body composition at an individual level (35), particularly in subjects with a BMI under 30 (36), and these may be amplified when longitudinal measures are conducted.

Although this study confirmed the high correlation between the SFT, BMI, BIA and deuterium dilution technique, Bland and Altman analysis revealed disagreement between these methods. Although most of the points on the Bland and Altman plots, particularly for the BMI and SFT measurements, fall within ±2SD, the range of error was from underestimation of 9.2% to overestimation of 12.6% of fat mass on the BMI technique and, similarly, for the SFT technique the range was from −14.3% to +5.9%, respectively. The range of error for BIA was underestimation of fat mass from 8.4% to 0.7%, compared to deuterium oxide dilution, thus these methods can not be used interchangeably, as the limits of agreement are quite wide for all the methods used.

At present, BIA is probably the most frequently used method of assessing BC, in the clinical setting, due mainly to the relatively inexpensive cost of the basic instrumentation, its ease of operation, and its portability. However, this method underestimates fat mass in morbidly Caucasian obese and type 2 diabetes subjects. The combination of segmental and multi-frequency bioimpedance methods may attract some benefits in terms of accuracy and the possibility of determining both FFM, FM and body shape variation within individuals and between ethnic groups. The advances in appendicular lean body mass assessment by segmental multi-frequency BIA in obese (37) and TBW in normal body weight subjects (38) are already available. These techniques would also facilitate the capacity to measure or estimate intra-abdominal and subcutaneous adipose tissue without having to utilize the expensive imaging techniques for differentiation of regional body composition. This is particularly required in diabetic and metabolic syndrome patients as they become a larger proportion of the general population.

CONCLUSION

This study was conducted in an obese Caucasian population to compare the bedside methods of body composition, namely, BIA, SFT and BMI against the D_2O dilution technique using a two-compartment model of body composition to assess body fat mass. BIA and SFT underestimated percentage of fat mass in all the obese subjects. Body mass index showed no difference in the estimated %FM in classes I and II of obesity but overestimated the percentage of fat mass in class III of obesity. Fat in legs, arms and trunkal area and waist to hips ratio were important determinants of the differences in body fat mass when comparing bedside techniques with deuterium oxide dilution in obese and type 2 diabetes subjects.

Thus, BMI and SFT could be used in subjects with moderate obesity, whereas BIA could be utilised in obese and obese type 2 diabetes patients in daily clinical practice. D_2O dilution should be considered as the method of choice, when the accuracy is particularly important. Furthermore, estimates of %FM from BIA or SFT could not be used interchangeably with D_2O, without the risk of considerable error.

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NUTUKUSIŲ IR NUTUKUSIŲ BEI ANTRO TIPO CUKRINIU DIABETU SERGANČIŲ ASMENŲ KŪNO SUDĖTIES MATAVIMAS: METODŲ PALYGINIMAS

Santrauka

Įvadas. Kūno sudėties (KS) ypatumai yra tiesiogiai susiję su įvairių ligų išsivystymo rizika. Ankstesniuose tyrimuose analizuojami onkologinėmis ligomis sergančių, nėščiųjų ar žmogaus imunodeficito virusu infekuotų asmenų KS nustatymo metodai, tačiau literatūroje nėra duomenų, lyginančių nutukusių ir nutukusių, II tipo diabetu sergančių asmenų KS tyrimo metodus, ypač atsižvelgiant į riebalų išsidėstymą tam tikrose srityse. Šio tyrimo tikslas buvo palyginti įprastus kūno sudėties tyrimo metodus – kūno masės indeksą (KMI), odos raukšlės matavimą (ORM) ir bioelektrinį impedansą (BIA) – su deuterio oksido (D_2O) praskiedimo metodu nutukusiems (N) ir nutukusiems, II tipo diabetu (N-CD) sergantiems asmenims bei nustatyti ryšį su riebalų pasiskirstymu tam tikrose srityse.

Medžiaga ir metodai. Kūno riebalų masė (KRM) buvo apskaičiuota naudojant D_2O praskiedimo metodą, ORM, BIA ir KMI 94 nutukusiems pacientams, iš kurių 53 sirgo II tipo cukriniu diabetu (CD).

Rezultatai. Naudojant BIA ir ORM buvo nustatyta atitinkamai 5,2% ir 6,1% ($P < 0,001$) mažesnė nutukusių KRM bei atitinkamai 3,9% ($P = 0.01$) ir 2,8% ($P = 0,037$) mažesnė nutukusių, sergančių II tipo CD KRM, lyginant su D_2O metodu. Naudojant KMI buvo nustatyta 3,2% ($P = 0,045$) didesnė tik nutukusių, II tipo CD sergančių asmenų KRM.

Taikant BIA skirtumas išliko stabilus tarp įvairaus svorio tiriamųjų, o taikant ORM, didėjo lygiagrečiai kūno svoriui.

Riebalų kiekis kojų, rankų bei juosmens srityje, taip pat liemens ir klubų santykis lėmė nutukusių ir diabetu sergančių asmenų KRM skirtumą lyginant įprastus KS tyrimo metodus su D_2O praskiedimu.

Išvados. KRM skirtumai, nustatyti lyginant BIA, ORM ir KMI su D_2O praskiedimo metodu, yra susiję su nutukusių ir sergančių II tipo CD pacientų riebalų pasiskirstymu tam tikrose srityse. KMI ir ORM gali būti naudojami kasdieninėje praktikoje vertinant I ir II nutukimo laipsnio asmenų kūno riebalus, o BIA tinka visiems nutukusiems asmenims, tačiau negalima pamiršti galimos šių metodų paklaidos didėjant kūno svoriui ir esant centrinio tipo riebalų pasiskirstymui. D_2O praskiedimo metodika gali būti pasirinkta, kai ypač svarbus mokslinių tyrimų tikslumas.

Kūno riebalų kiekį nustatančių BIA, KMI ar ORM metodų naudojimas, keičiant juos tarpusavyje ar su D_2O metodu, gali lemti ryškias papildomas paklaidas, todėl tam pačiam pacientui ilgalaikiam stebėjimui reikėtų taikyti tą patį tyrimo metodą.

Raktažodžiai: kūno sudėtis, deuterio oksido praskiedimas, nutukimas, diabetas