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Measurement of Body Fat Mass, Fat-Free Mass, and Muscle Mass Measured using Bioelectric Impedance and Dual-Energy X-Ray Absorptiometry

Farah N. Mohammed Ali
Department of Physics/ College of Science/ University of Mosul
E-mail: farahnathim@gmail.com
Khalid G. Majeed
Department of Physiology/ College of Medicine/ University of Ninevah
E-mail: khalid_ghanim63@yahoo.com
Firas M. A. Al-Jomaily
Department of Physics/ College of Science/ University of Mosul
E-mail: dr.firas@uomosul.edu.iq

ABSTRACT

In this research, we discussed the bone density by measuring the total bone mineral density, fat mass and lean mass in a sample of Mosul people, as soon as to compare the accuracy of the BIA approach to DXA in assessing total body compartments and segmental tissue mass. A cross sectional study conducted at DXA laboratory, Physiology Department, College of Medicine, Nineveh University, Mosul-Iraq. A total of 136 persons, 44 males and 92 women, recruited from reviewing of college Medical College Academic Centre and took part in the current study. A highly statistically significant association between BIA and DXA measures for TFM, TLM, and FFM was also found. BIA underestimates total fat mass by 7.24 kg than DXA. BIA approach overestimated muscle mass by 10.1 kg when compared to the DXA. BIA underestimates fat-free mass by 20.67 kg compared to DXA.

Keywords: Dual energy X-ray absorptiometry, bioelectrical impedance analysis, body mass index, bone mineral density.

INTRODUCTION

It is commonly recognized that physical form has a distinct impact on happiness. As a result, body composition analysis is frequently used in clinical practice to assess and control dietary intake, such as in obesity and malnutrition research (Tylavsky *et al.*, 2003). For the treatment of excess fat mass, determining the size of body fat is also necessary. Several studies have been conducted, ranging from analyzing an individual's nutritional state to determining the nature of his or her response to a variety of diseases and metabolic disorders (Kalkwarf *et al*., 2003). Because it is so closely linked to human physiology and disease, the body structure has a wide range of applications in diet, exercise physiology, medicine, geriatrics, and health. The most prevalent methods for assessing body composition are hydro densitometry, air displacement plethysmography, skinfold measurements, bioelectrical impedance analysis (BIA), and dual-energy X-ray absorptiometry (DXA). (Rodrigues Filho *et al*., 2016), (Sampriti *et al.*, 2018), (Tomlinson *et al*., 2019). In recent years, BIA has grown in popularity in clinical practice, epidemiological research, and among individuals on a personal level due to its non-invasive, easy-to-use, and handy nature (Rodrigues Filho *et al*., 2016). BIA measures the water compartment's electrical impedance to the flow of single or multi-frequency currents. Najate Achamrah (Achamrah *et al*., 2018). However, because the human body is not a homogenous cylinder, predicting body composition from impedance requires a number of assumptions as well as a sophisticated regression equation for the target population. (Rodrigues Filho *et al*., 2016). Clinical medical evaluations revealed that all of the participants were in good health. People who had chronic medical illnesses, were taking medications that affected bone metabolism, or had a family history of osteoporosis, as well as smokers, were excluded from the study.

The aim of the study is to evaluate total fat mass, total muscle mass, and total fat-free mass in a sample of Mosul people, as well as to compare the accuracy of the BIA approach to DXA in assessing total body compartments and segmental tissue mass. The total body compartments prediction equations based on segmental portions of the body and BMD distribution were also researched and discussed.

MATERIAL AND METHODS

From July 1, 2020, to April 30, 2021, the study was done at the Medical Physics Unit / DXA laboratory at the Department of Physiology, College of Medicine, Nineveh University, Mosul, Iraq. A group of healthy adults who volunteered to take part in the study. The ethics committee at Nineveh University's College of Medicine approved the study's ethical approval (Mosul, Iraq). Written informed consent forms were given to all participants in this investigation. A total of 136 persons, 44 males and 92 females, took part in the current study. In a supine position, DXA measures of soft tissue composition were taken. It takes 12 to 15 minutes to scan the entire body. The scanner is a prospective X-ray generator that uses the DXA type Stratos Bone Densitometer scanner to produce two energy levels of (40-70) keV. (Stratos from DMS group, France). Aggarwal, 2016). During scanning, patients were required to wear hospital gowns and remove all metal jewelry (Aggarwal and Ranganathan, 2016). In kilos, the scanner delivers. scanner delivers direct whole and segmental body fat mass. Also calculated the total and segmental fat mass, fat-free mass, and predicted muscle mass. The soft tissue composition was measured using BIA in a standing position with abducted arms and legs, which took about a minute. Bioelectrical impedance is recorded utilizing an eight-contact electrode system Model BC– 418 analyzers to estimate whole-body and segmental fat mass (Tanita Corp., Tokyo, Japan). At 50 kHz, measurements are authorized. The apparatus provides a direct estimation of entire fat mass and body composition in the human body (kg).

RESULTS AND DISCUSSIONS

In the study, which included participants from the Mosul city population in Iraq, we evaluated our evaluated our findings utilizing both DXA and BIA techniques for measuring and assessing body composition. A total of 136 men and women, 44 men and 92 women, took part in the current study. (Table 1) shows descriptive information for the subjects based on their anthropometric measures.

Table 1: Descriptive characteristics of the participants

Characteristics	Minimum	Maximum	Mean	Std. Deviation
Age (year)	18.00	76.00	44.76	14.86
Height (m.)	1.46	1.82	1.62	0.08
Weight (kg)	34.40	115.90	75.47	16.67
BMI (kg/m^2)	20.30	50.80	28.81	5.77

(Table 2) displays the body mass index (BMI) distribution by gender for all study groups, as well as the percentages for each group.

Table 2: BMI distribution among each subgroup

BMI Classes	Male		Female	
	N=44	No. (%)	N=92	No. (%)
Normal	10	(22.7%)	20	(22.2%)
Overweight	22	(50.0%)	40	(44.4%)
Obese	12	(27.3%)	30	(33.3%)

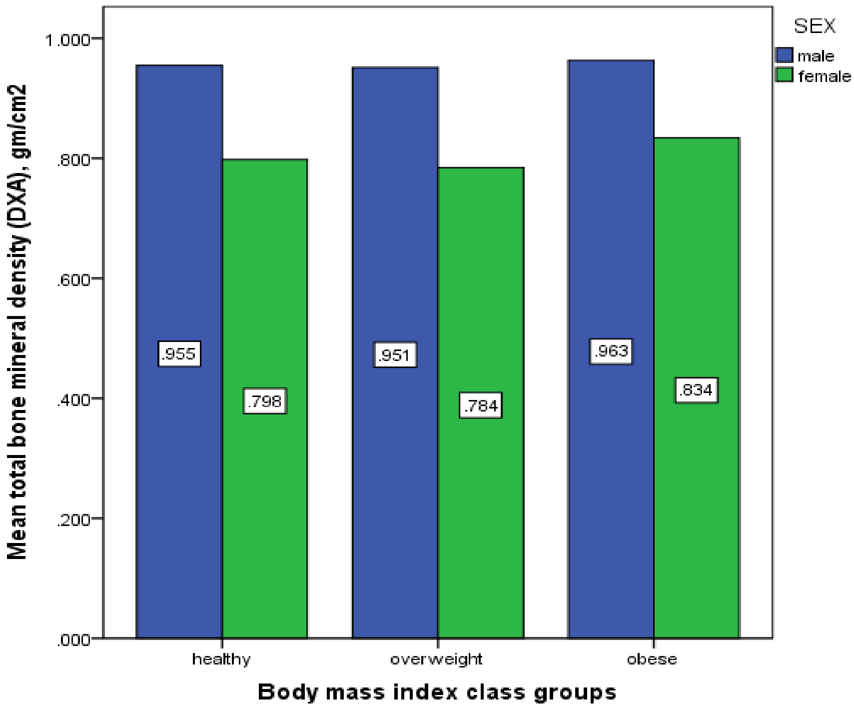

Fig. 1: Graphical plot for the amount of total BMD distribution according to BMI.

The amount of bone mineral density among the participants according to the body mass index (BMI) of the three groups (health, overweight, and obesity). According to gender is depicted graphically in Fig. (1). For all BMI category groups, the amount of BMD in females is smaller than in males, as seen in the graph. Through male and female, it is equal to 0.95 g/cm^2, 0.75 g/cm^2 for healthy subgroup, 0.95 g/cm^2, 0.78 g/cm^2 for overweight subgroup, and 0.96 g/cm^2, 0.83 g/cm^2 for obese subgroup. The obese subgroup had a greater one, according to the findings.

The T-score distribution among the participants according to the body mass index (BMI) of the three cases (health, overweight, and obesity) is shown in (Table 3).

The results showed that the overweight subgroup had the lowest T- score, as shown in the graph above.

Table 3: T- score evaluation for all subgroups

T- Score	Male ± SD	Female ± SD
Healthy	-1.64 ± 0.78	- 1.85 ± 0.36
Overweight	-1.97 ± 0.50	-1.97 ± 0.71
Obese	-1.90 ± 0.67	- 1.51± 0.43

For all study groups, the findings of the T-score for the entire body from the class of osteopenia for both males and females. Fig. (2) shows scattered figures utilizing DXA scan that revealed a good correlation between the T-score of the total body and the Z-score distribution among all individuals, with R^2 =0.66.

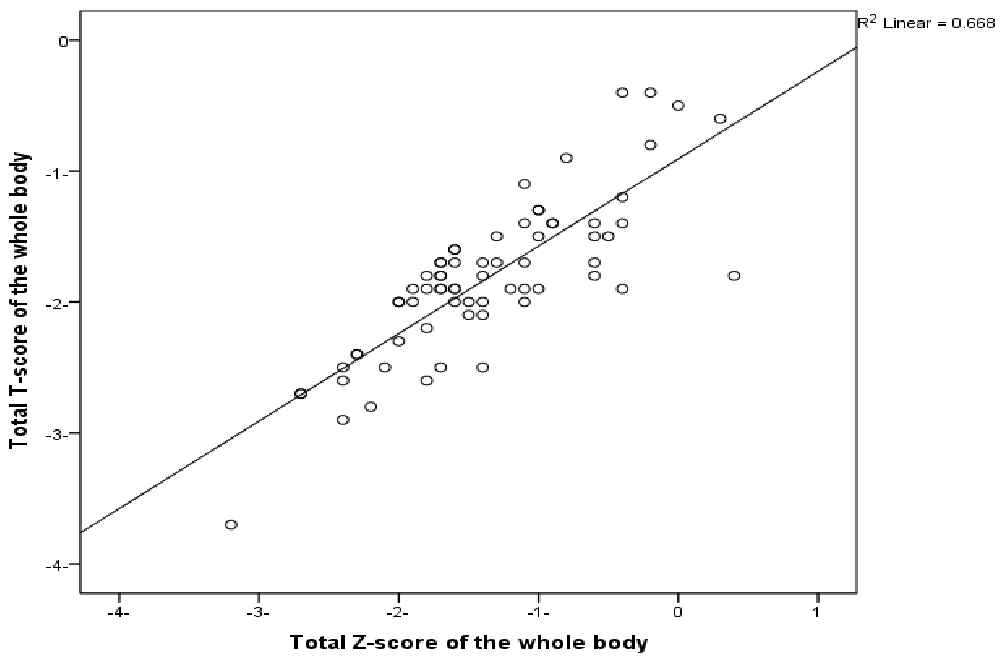

Fig. 2: the correlation between T-score and Z-score for the whole body

Soft Tissues Calculations

The correlation between total lean mass and segmental lean compartments of the body are shown in Fig. (3–5) (p<0.0001).

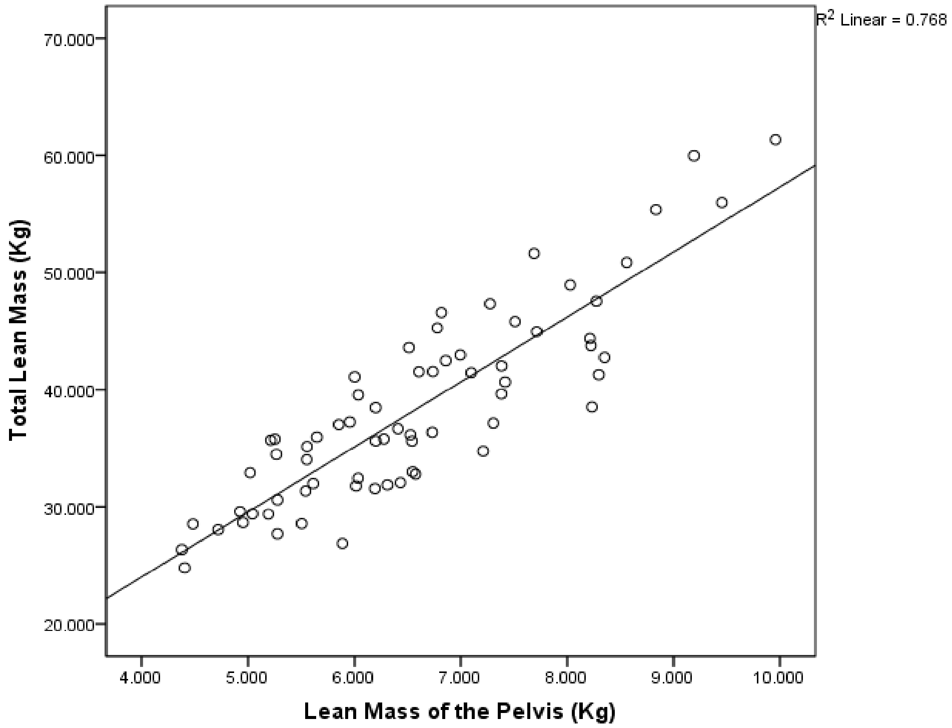

Fig. 3: **Correlation between total lean mass and segmental lean mass of the Pelvis**

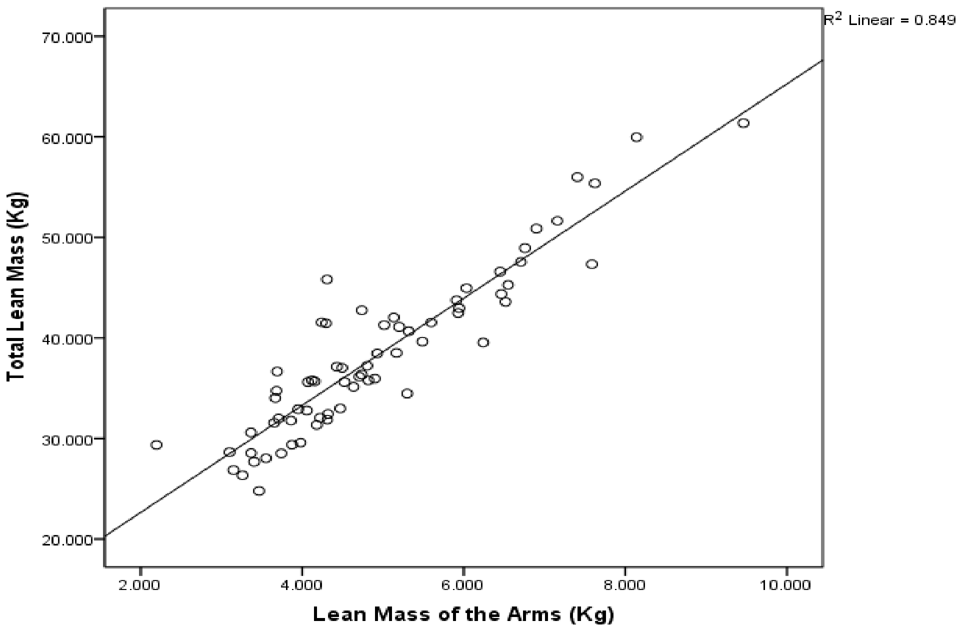

Fig. 4: **Correlation between total lean mass and segmental lean mass of the arms**

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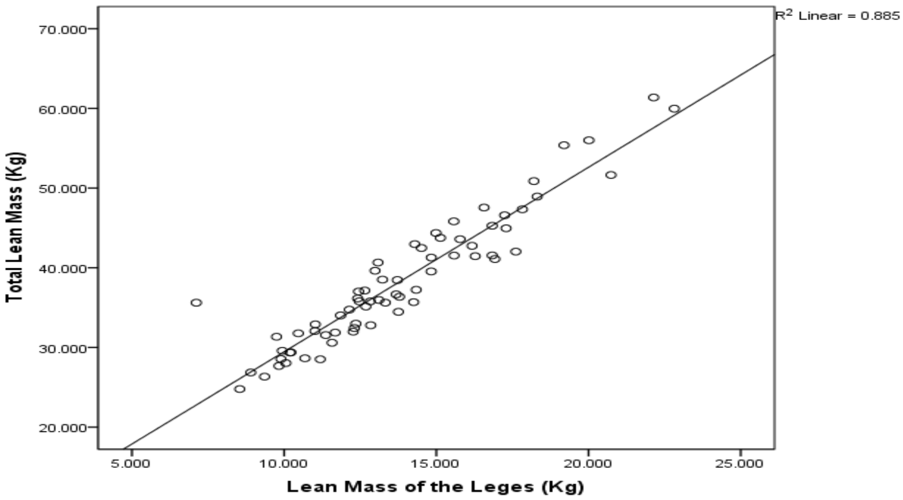

Fig. 5: **Correlation between total lean mass and segmental lean mass of the legs**

The following formula was used to calculate total muscle mass (BIA) in our study (Majeed, 2019). Total muscle mass (BIA) = predicted muscle mass of right arm+ predicted muscle mass of left arm+ predicted muscle mass of right leg+ predicted muscle mass of left leg+ predicted muscle mass of the trunk as shown in the Figs. (3-5). A scattered plot and fitted regression lines between both total fat mass and segmental fat mass of the arms are depicted in Fig. (6) $p<0.0001$.

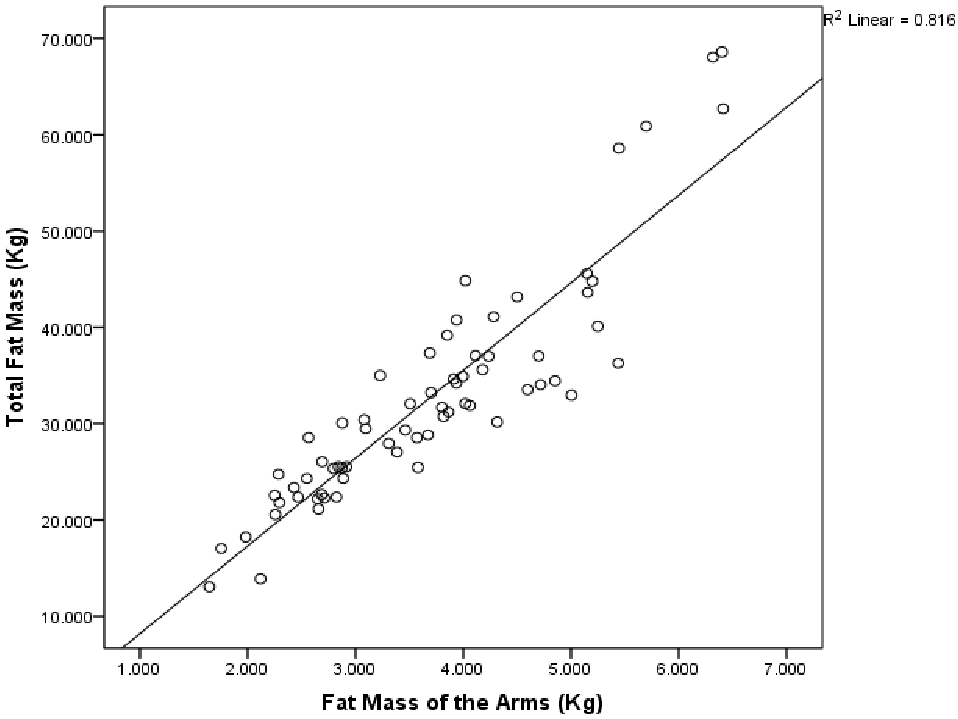

Fig. 6: **Correlation between total fat mass and segmental fat mass of the arms**

A scattered plot and fitted regression lines between both total fat mass and segmental fat mass for the arms, pelvis and legs respectively are depicted in Figs. (6-8) p<0.0001.

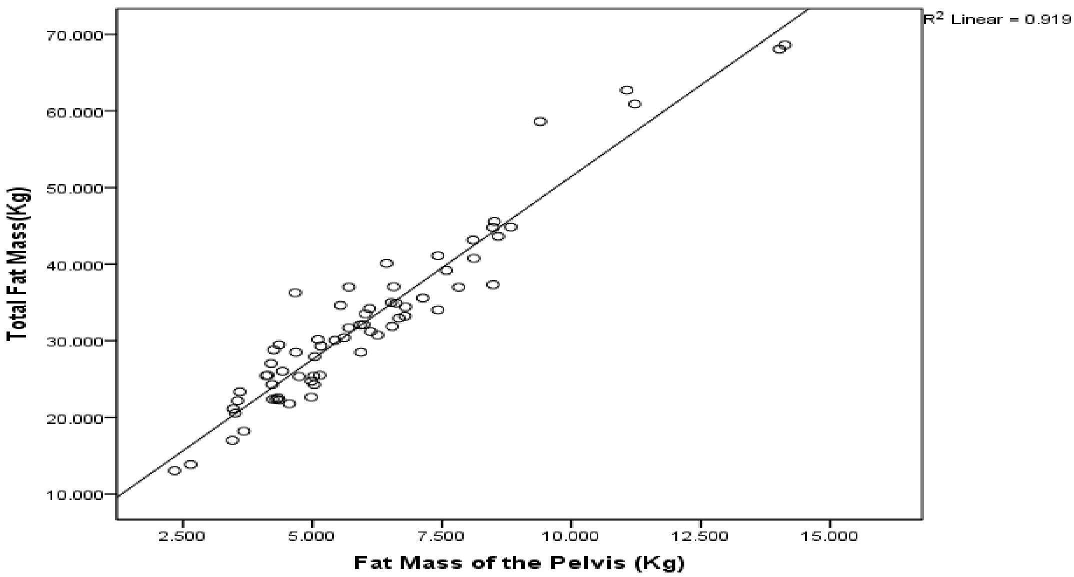

Fig. 7: **Correlation between total fat mass and segmental fat mass of the pelvis.**

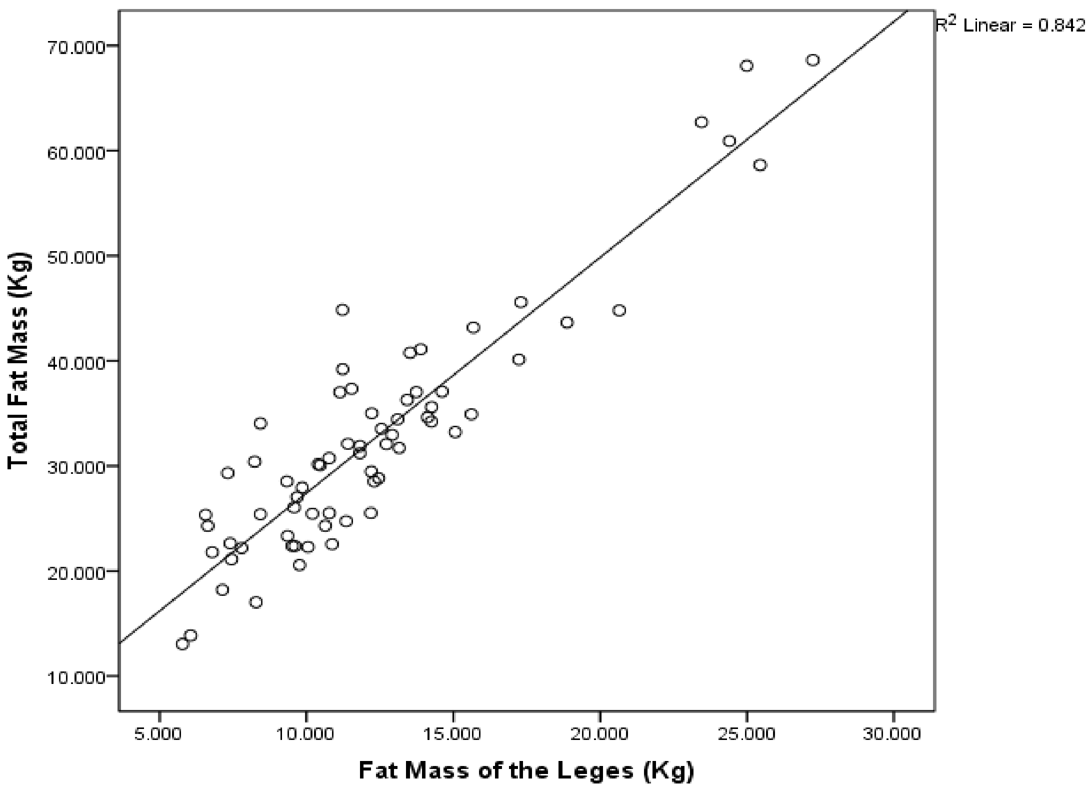

Fig. 8: **Correlation between total fat mass and segmental fat mass of the legs.**

DXA and BIA Measurements

Table 4: shows the variations in body composition measured using both approaches

Variables	DXA, Mean± SD N=136	BIA Mean± SD N=136	Pearson correlation(R)	R^2	P-Value
Total lean mass, Kg	38.24 ± 8.11	48.34 ± 9.41	0.93	0.87	0.0001
Total fat mass, Kg	32.63 ± 11.55	25.39 ± 10.92	0.95	0.91	0.0001
Fat free mass, Kg	70.88 ± 15.34	50.21± 9.90	0.80	0.48	0.0001

The main differences in total body compartment mass estimates between BIA and DXA are shown in Table 4. For both total fat mass and total fat-free mass, BIA estimates were considerably lower than DXA estimates (p-value<0.0001). The following were the average differences: total fat mass difference (7.24) kg; total fat free mass difference was (20.67). The estimations of BIA were significantly higher than those by DXA for total lean mass (p-value <0.0001). Since the difference in total lean mass (-10.1) kg. For total lean mass, DXA estimates were considerably lower than BIA estimates (p-value<0.0001). (Table 4) shows the correlation and regression analysis used to evaluate the performance of both the BIA and DXA measurements. Figs. (9) through 11 show the scattered plot and fitted regression lines to estimate total body compartments using both BIA and DXA methodologies (13). Body fat mass (regression coefficient, R^2=0.91) was found to be the best fit line for both tests. While the fitting line of both tests was found in the estimation of total muscle mass and total fat free mass (regression coefficient, R2 were 0.87 and 0.48). Thus, 91% of BIA measurement of total fat mass is explained by DXA. In other words, 87% of BIA measurements of total muscle mass are explained by DXA. However, slightly less than half of variation in total fat free mass is explained by DXA estimation.

The mathematical models below can be used to correct DXA estimates of various body compartments to obtain corresponding BIA estimates (p-value<0.0001):

Total fat mass in BIA=- 4.19+0.90 (Body Fat Mass in DXA) ……..(1)

Total Fat-free mass in BIA=18.31+0.45 (Body Fat-Free Mass in DXA) ……(2)

Total muscle mass in BIA=0.26+0.55 (Body muscle Mass in DXA) …………(3)

The above mathematical models were calculated using this formula:
Dependent variable = constant (B_0) + (B_1) *(independent variable "segment part")
However, it is equal to;

$$Y = B_o + B_1 X \quad \text{…………………..(4)}$$

where Y represents the value of the variable being predicted, B_0 is the y-interception, B_1 is the slope of the straight line, and X is the known value of the independent variable (segment portion).

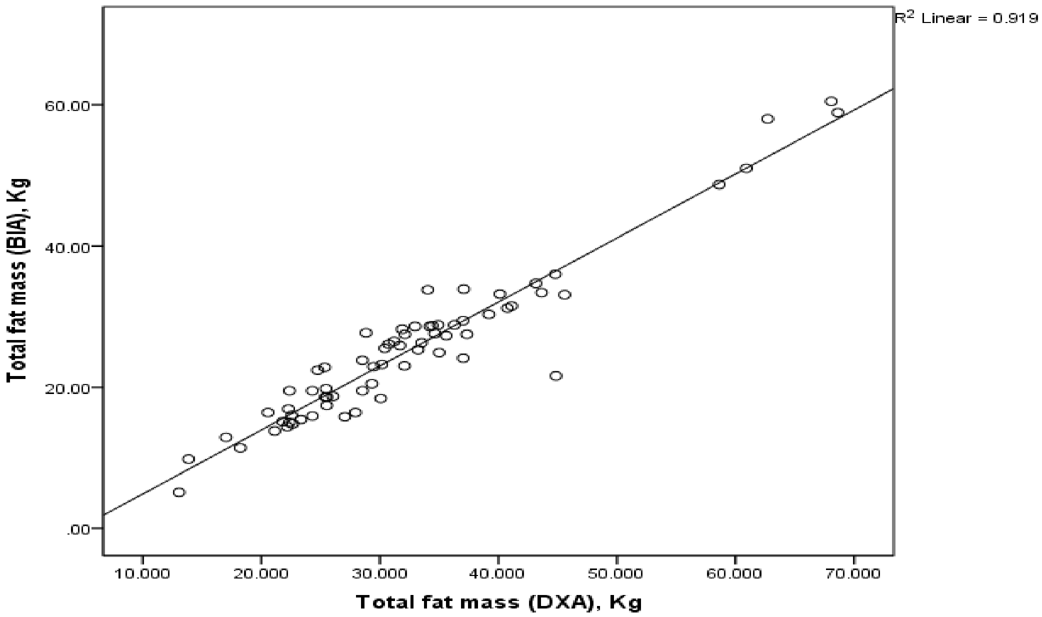

Fig. 9: The relation between the body fat mass estimated by (BIA) and (DXA) methods.

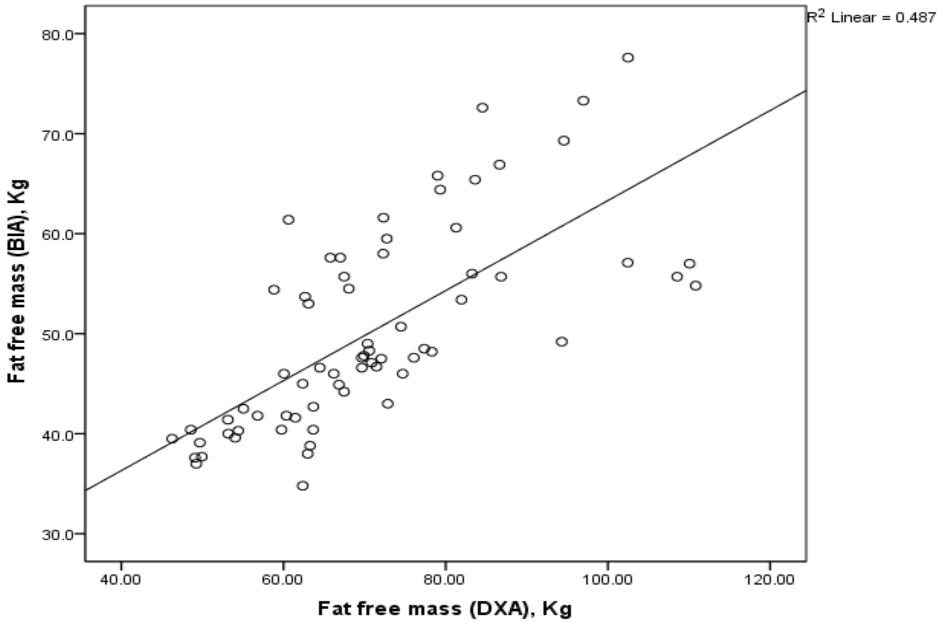

Fig. 10: The relation between the body fat-free mass estimated by (BIA) and (DXA) methods.

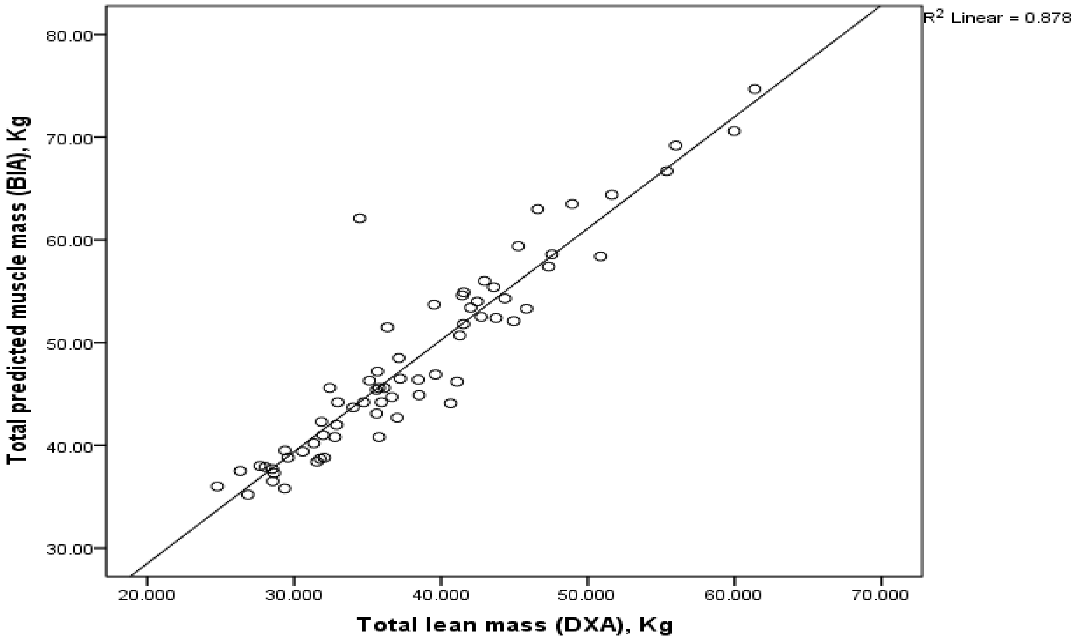

Fig. 11: The relation between the total body lean mass estimated by (BIA) and (DXA) methods.

This study provides new insight into the bone mineral content, bone mineral density, T-score, and Z-score of Mosul population of men and women. Quantitative ultrasonography, x-ray radiography, and invasive Quantitative computed tomography QCT-scan were utilized in previous investigations (Marra *et al*., 2019), (Poehlman *et al*., 2002) (Peltz *et al*., 2010). In this study, we used both modern Dual-energy X-ray Absorptiometry (DXA) technique and BIA to analyze segmental and total body composition to show the differences in the body tissue measurements according to the usage the two machines for both genders. This is the second scientific study on the Iraqi level that deals with the accuracy of body composition measures and their comparison through the use of two separate instruments (DXA and BIA). The DXA uses dual-energy X-ray absorption technology, whereas the BIA employs electrical impedance technology. However, using a DXA technology that uses a tiny dosage of X-ray to obtain extremely accurate measures of bone health of segmental and total body composition is beneficial (Silva *et al*., 2014).

Leg-to-leg BIA, according to Miyatani *et al*., can be utilized to make a routine assessment with DM type 2 and measure body composition analysis (Miyatani *et al*., 2012). Other studies found that using a BIA device to assess body composition in obese people and people with cardiometabolic illnesses was effective, practical, and a good approach (Ugras, 2020). The current study was the highly selective criteria used in recruiting the current study sample (normal overweight BMI class; (28.81 ± 5.77) kg/m^2 with ethnic of Middle eastern sample. Obese people had the highest bone mineral density, followed by overweight people, and healthy people had the lowest. This is totally in line with the information supplied by (Siddapur *et al*., 2015). The final calculation yield of the T-score for the total body from the osteopenia class revealed that the overweight class had the lowest T-score for both genders, which is consistent with (Miyatani *et al*., 2012) utilizing DXA technology. Previous research has attempted to compare the accuracy of skinfold thickness to DXA as gold standards in assessing total body fat in a variety of groups (Aggarwal and Ranganathan, 2016). Meanwhile, several researchers employed the DXA and BIA procedures to determine the amount of body fat (Achamrah *et al*., 2018). The findings revealed a discrepancy in their research findings. Some researchers concluded that the BIA overestimates fat and fat-free mass composition, whereas others concluded that the BIA underestimates fat mass composition (Bolanowski and Nilsson, 2001), (Majeed *et al*., 2019). A highly statistically significant correlation between BIA and DXA measures for TFM, TLM, and FFM (p-value 0.0001) was also founding. Total fat mass had the strongest correlation (r=0.95, p-value 0.0001). In a sample of 100 Swedish patients, Bolanowski et al show high agreement in body fat estimates between BIA and DXA (Bolanowski, 2001). All of the linear regressions for BIA prediction in TFM, TLM, and FFM using DXA were statistically significant, with p< 0.0001. Leahy S et al concluded that BIA overestimates fat composition (Leahy, 2012), other researchers concluded that BIA underestimates fat composition (Neovius, 2006). According to the findings of this study, BIA underestimates total fat mass by 7.24 kg. This figure is close to that reported by Bolanowski *et al.*, (6.5 kg) (Bolanowski, 2001). It was, however, far higher than the result reported by Volgyi *et al.*, (Volgyi *et al*., 2008), which was 4.3 kg lower than DXA.

Our findings demonstrated that the BIA approach overestimated muscle mass by 10.1 kg when compared to the DXA approach. This is because the total body water contained in lean body tissue causes the quantity of lean mass measured by BIA to be greater than that identified by DXA. It was, however, 5.0kg more than the figure reported by Bolanowski *et al*., (Bolanowski, 2001). On the other hand, our analyses reveal that BIA underestimates fat-free mass by 20.67 kg compared to DXA. This high level of agreement result was mentioned by (Berstad *et al*., 2012). Since they used their study in University of Limerick Research, Leahy et al discovered that BIA was overstated by 2.0 kg in the female group (Leahy *et al*., 2012). Nana et colleagues also find that among a group of obese adolescents, the difference is somewhat more than 2 kg (Nana *et al*., 2012).

CONCLUSIONS

In this study, we used two techniques (BIA and DXA). DXA machine used to detect Bone content, bone mineral density, T- score, Z score, and the body compositions by using two energies. BIA tool used to measure total and segmental body compositions like fat mass, predicted muscle mass, and fat-free mass using the bioelectric impedance of the body. Every tool can detect body composition differently. The study aimed to evaluate the total fat mass, total muscle mass, and total fat-free mass in a sample of Mosul people using both techniques. A correlation was also found between total and segmental bone mineral density (BMD). Comparing the accuracy of the BIA approach to DXA in assessing total body compartments and segmental tissue mass. The measurements of the total body compartments based on segmental portions of the body distribution were also and discussed. The correlation between the total and segmental bone mineral density (BMD) was calculated. The relation of the total body compartments based on the segmental parts of the body and the distribution of BMD were also studied. Furthermore, the assessment of the linear regression between total fat mass, muscle mass, and fat-free mass between (BIA and DXA) technique were calculated. New mathematical models were founding and used to correct DXA estimates of various body compartments to obtain corresponding BIA estimates.

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قياسات كتلة الشحوم الكلية والكتلة الخالية من الشحوم وكتلة العضلات باستخدام جهازي الممانعة الكهربائية للجسم وامتصاص اشعه اكس ثنائي الطاقة

الملخص

قمنا في هذا البحث، بدراسة كثافة العظام وقياس الكثافة المعدنية للعظام، كتلة الشحوم وكتلة العضلات لمجموعه من مواطنين من مدينة الموصل، وكذلك مقارنة دقة القياسات باستخدام جهازBIA وكذلك جهازDXA في تقييم كتلة الأنسجة الجسمية والجزئية في الجسم. اجري البحث كدراسة مقطعيه في مختبر هشاشة العظام DXA (الدكسا) التابع لفرع الفسلجة/ كلية الطب/ جامعة نينوى/ مدينة الموصل. تم تجميع عينه مكونه من 136 شخصا هم 44 ذكور و92 من الاناث ممن يراجعون المركز الطبي في الكلية. لوحظ وجود ارتباط احصائي معنوي باستخدام قياسات جهازي DXA وBIA عند دراسة كتلة الشحوم الكلية وكتلة العضلات الكلية وكذلك الكتلة الخالية من الشحوم. اظهرت الدراسة بان هناك تقديرات منخفضه في قياس الكتلة الكلية للشحوم بمقدار 7.24 كغم المقاسة بجهاز BIA مقارنة بجهاز ال DXA. بينما كانت قياسات BIA لكتلة العضلات الكلية ذات تقديرات مرتفعة بمقدار 10.1 كغم مقارنة مع جهاز ال DXA. في حين ان التقديرات كانت منخفضه لقياس الكتلة الخالية من الشحوم والمقاسة بجهاز BIA بمقدار 20.67 كغم مقارنة مع جهاز DXA.

الكلمات الدالة: امتصاص الاشعة السينية ثنائي الطاقة، الممانعة الكهربائية للجسم، مؤشر كتلة الجسم، الكثافة المعدنية للعظام.