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Full Length Research Paper

The bioelectrical impedance analysis with newly predictive equations for measuring segments body composition of elite male football players in Taiwan

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To establish the appropriate predictive equations of body segments by bioelectrical impedance analysis (BIA) in Taiwan elite male football players, 26 disciplined players at first grade in collegiate league have been recruited in this study. The measurement data by our newly developed predictive equation was compared with Tanita BC-418 to confirm the greater performance in prediction of body composition in our equation. The actual analyzed data of segments body composition by dual-energy X-ray absorptiometry (DXA) was taken as reference one. Both of the correlation coefficients of whole body fat free mass (FFM) measured by DXA between BC-418 as well as that of our newly developed predictive equation were over 0.95. However, the correlation coefficients of upper limb, lower limb and truck FFM measured by predictive equation highly correlated to that of the reference DXA were 0.75, 0.76 and 0.89, respectively. They all were better than that of BC-418 measurement. In summary, the greater performance in prediction of segments body composition in our developed predictive equation by BIA measurement has shown the possibility of application for monitoring athlete body composition especially the limb and trunk.

Key words: Dual-energy x-ray absorptiometry, fat free mass, body composition.

INTRODUCTION

Weight control is an important topic for athlete performance during exercise training. (Hendler et al., 1995; Oppliger et al., 1995; Roemmich and Sinning, 1997). Different sport items, even the different roles played in the same sport (for example, running vs. blocking in football), require specific body characteristics types. Using absolute body weight as the only parameter alone to define the specific characteristics of body composition is vulnerable to occurrence of errors not only to general people but also to athletes. As the view of athlete weight control, the index as changes in body fat (BF), fat free mass (FFM) and body composition are more precise and meaningful than as absolute changes in total body weight values only. It would be beneficial to promote exercise performance that the possession of BF and FFM on athlete health management and modulating training prescription and weight-modifying diets before competition (Mäestu et al., 2010). In other words, the exercise performance is closely relative to the athlete's body composition or body type. In the football players, assessed for body mass, BF,

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Table 1. Characteristics of the subjects in the present study.

Variable	Mean (n = 26)	SD.
Age (year)	20.65	1.85
Body height (cm)	173.96	5.57
Body weight (kg)	66.13	5.16
Body fat measured by DXA (%)	9.75	2.89
Body mass index (BMI) (kg/m^2)	21.84	1.09

$\dot{V}O_2$ max (maximal oxygen uptake), leg power, anaerobic capacity and speed prior to an English league season, thirteen goalkeepers players exhibited lower $\dot{V}O_2$ max and higher BF than that of full-backs, centre-backs, mid-field players and forwards groups as higher $\dot{V}O_2$ max and lower BF. Moreover, the forwards, with the relatively lower BF have the fastest performance than goalkeepers or centre-backs and full-backs (Davis et al., 1992). In addition, greater athletic speed performance, strength advantage and fast movement through space are relative to lower body compositions have been well published (Davis et al., 1992; Sergej, 2003; Luis et al., 2004).

Body composition refers to the relative of FFM, BF, bone and other tissue of which the body is composed. Additionally, body composition measurement could give assistance to monitor nutrition status and training prescription on elite athlete. According to the important meaning of body composition on general people and on athlete, the research of body composition assessment was respected and its progress is like a raging fire. Up till date, the DXA is the most accurate method among all the body combination measurements (Avesani et al., 2004; Prior et al., 1997). However, there are complicated practice and expensive limitations on the DXA measurement, so as to retard performing this method on the athlete. The convenient, accuracy, non-invasive, simple, quick and non-expensive characteristics rendered the wildly usage by BIA method to predict the body composition such as BF, FFM, total body water (TWB) (Kyle et al., 2004a, b), skeletal muscle mass (SMM) (Janssen et al., 2000), extracellular water (ECW) (Deurenberg et al., 1995), intracellular water (ICW) (De Lorenzo et al., 1995), visceral fat (Ryo et al., 2005), subcutaneous adipose tissue (Fernandes et al., 2007) and phase angle (Baumgartner et al., 1988). The BIA measurement with predictive equation for body compositions in athletes should be specifically developed rather than be fitted to normal health man (Kyle et al., 2004). In addition, athletes have different body built on different sports or different roles in the same sport item; accordingly, each sport item must develop the specifically evaluating equation for body composition. Predictive equations of DXA and BIA for general people used to predict the BF of athletes have shown the relative lower R value about 0.62 (Stewart and Hannan, 2000). There was low correlation between underwater weight and Tanita BIA (TBF-305) on less activity, moderately active and highly active male athlete (Swart et al., 2002). Skinfold equations incorporating anterior thigh, abdominal, triceps and medial calf sites were accounted for 78.4% variance by regression analysis referenced with DXA criterion values in forty-five professional soccer players (Reilly et al., 2009). Therefore, the Tanita, BC-418 was designed with two selectable modes could either be for general people or for athletes. In addition, the BC-418 was designed to perform in standing position.

There are differences between the BIA performed in supine position and in standing position for different posture performing different bioelectrical impedance (Kriemler et al., 1996). Presently, no appropriately specific way can evaluate the body composition of athletes accurately. We tried to establish appropriate body composition predictive equations with body height, each segment weight and related impedance on Taiwan elite football male players. The validity of our predictive equations will be compared with the athlete mode of BC-418 and DXA.

MATERIALS AND METHODS

Subjects

The 26 elite male football players who are the first grade in collegiate league and were disciplined for 15 h per weeks over 7 years were recruited with formal consents under the permission of institutional review board (IRB) of advisory committee at Jen-Ai Hospital in Taiwan. All the details about experimental purpose, methods, procedures, steps and any safety relative comments were well informed to all the subjects before the proceeding of study. No alcoholic beverages were consumed for 48 h, no diuretic agent was administered for 7 days and no urination for 30 min before the examination of BIA and DXA measurements were allowed. The basic physical characteristics of subjects were shown in Table 1. The segmental body compositions of subjects were measured by DXA (Lunar Prodigy, GE Corp, USA.) with the software “enCore 2003 Version 7.0” and BC-418 (Tanita Corp, Tokyo, Japan). The whole body including head, skull, upper limb, lower limb and trunk, scanning protocol on DXA were performed at 20 μGy to each subject. Both of the whole BF and whole FFM were estimated by DXA performed at 50 kHz, 400 μA; consequently, the BC-418 measurement selected with athletes mode by standing up at platform embedded with tetra-polar electrodes and by griping a handle embedded with bi-polar electrodes. The bioelectric impedance, FFM and BF of each body segment were evaluated by BC-418. The values of bioelectric impedance (Z) of each body segment from athlete subjects by BC-418 were combined with age,

Table 2. The bioelectrical impedance (BI) and fat free mass (FFM) of elite football players in Taiwan estimated by BC-418.

	Mean	SD.	Range		
Bioelectrical impedance (ohm)					
Left upper limb	319.85	28.16	263	-	387
Right upper limb	309.77	23.63	273	-	362
Left lower limb	217.27	18.56	192	-	265
Right upper limb	215.92	19.33	189	-	261
Trunk	N.D.				
Whole body	556.58	44.89	475	-	675
Fat free mass (kg)					
Left upper limb	2.97	0.31	2.4	-	3.8
Right upper limb	3.15	0.28	2.6	-	3.8
Left lower limb	12.53	1.02	10.4	-	14.6
Right upper limb	12.41	0.93	10.4	-	14.1
Trunk (head + trunk)	28.73	2.32	23.7	-	32.7
Whole body	59.80	4.47	49.9	-	68.6

N.D.: unable to be detected by BC-418

body height and each body segments weight parameters to develop our predictive equation for athlete's body composition. All the measurements were carried out in Department of Radiology, Dah Li County Jen-Ai Hospital in Taiwan.

Statistical analysis

All the data were analyzed by SPSS.12.0 software (SPSS Inc., Chicago, IL, USA). Results are presented as mean ± SD (standard deviation). R values calculated from linear regression analysis and Pearson were expressed to describe the correlation between any variability. By using the linear regression equation, we followed the program suggested by Bland and Altman (1986) to survey the variability and distributions between FFM values estimated by the aforementioned correlation equations versus FFM values measured by whole body DXA. A confidence level of 5% ($p < 0.05$) was considered significant.

RESULTS

The mean value of BMI and BF measured by DXA was 21.84 ± 1.09 kg/m^2 and 9.75 ± 2.89%, respectively (Table 1). The subjects' mean age was 20.65 ± 1.85 years old, height 173.96 ± 5.57 cm and body weight 66.13 ± 5.16 kg (Table 1). The body composition and bioelectrical impedance of each limb or trunk estimated by BC-418 established equation were shown in Table 2. The FFM and BF of each limb or trunk on subjects evaluated by BIA were summarized in Table 2 and DXA in Table 3. For establishing FFM ($FFM_{lower\text{-}limb}$, $FFM_{upper\text{-}limb}$ or FFM_{whole}) evaluating equation, body weight (W) alone with body height (H) and limb impedance ($Z_{lower\text{-}limb}$ or $Z_{upper\text{-}limb}$) were performed linear regression analysis and described as Equation 1 in $FFM_{upper\text{-}limb}$, Equation 2 in $FFM_{lower\text{-}limb}$ and Equation 3 in FFM_{whole}, respectively. The evaluating equation of trunk:

(trunk + head) FFM (FFM_{trunk}) was equal to the FFM_{whole} - 2 × $FFM_{upper\text{-}limb}$ and 2 × $FFM_{lower\text{-}limb}$ as shown in Equation 4.

$$FFM_{upper\text{-}limb} = -0.746 + 0.028\ H^2/Z_{upper\text{-}limb} - 0.003\ Y + 0.017\ W, \quad (R = 0.737, SD = 0.31\ kg, p < 0.01) \quad (1)$$

$$FFM_{lower\text{-}limb} = -0.044 - 0.005\ H^2/Z_{lower\text{-}limb} - 0.054\ Y + 0.203\ W, \quad (R = 0.776, SD = 0.82\ kg, p < 0.01) \quad (2)$$

$$FFM_{whole} = -1.146 + 0.212\ H^2/Z_{whole} - 0.187\ age + 0.780\ W, \quad (R = 0.952, SD = 1.71\ kg, p < 0.01) \quad (3)$$

$$FFM_{trunk} = FFM_{whole} - 2\ FFM_{lower\text{-}limb} - 2\ FFM_{upper\text{-}limb}, \quad (R = 0.893, SD = 1.187\ kg, p < 0.01) \quad (4)$$

H: body height (cm).
W: body weight (kg).
Y: age (years).
Z: bioelectrical impedance (ohm).
FFM: fat free mass (kg).

The intercept, slope, SD and correlation coefficient of regression equations of $FFM_{upper\text{-}limb\ (BC418)}$, $FFM_{lower\text{-}limb\ (BC418)}$ and $FFM_{whole\ (BC418)}$ vs. of $FFM_{upper\text{-}limb\ (DXA)}$, $FFM_{lower\text{-}limb\ (DXA)}$ and $FFM_{whole\ (DXA)}$, respectively that were shown could be well illustrated in Table 4. Both of the correlation coefficients whole body measurements between DXA and our newly developed predictive equation (PEq.) as well as that of BC-418 were as high as 0.95. However, the correlation coefficients of upper limb, lower limb and truck between DXA by PEq. were 0.75, 0.76 and 0.89 which have greater predictive performance than that of BC-418 measurement. All the correlation coefficients between PEq. and DXA measurement in limb or trunk were higher than that of BC-418 measurement. After surveying the following program adopted by Bland and Altman, we can

Table 3. The fat mass, fat free mass (FFM) and body fat (BF) of elite football players in Taiwan measured by DXA.

Variable	Fat mass (kg)		Fat free mass (kg)		Body fat (%)	
	Mean	**SD.**	**Mean**	**SD.**	**Mean**	**SD.**
Right upper limb	0.16	0.06	2.97	0.41	5.18	1.61
Left upper limb	0.16	0.06	2.94	0.44	5.17	1.61
Right upper limb	1.19	0.49	11.63	1.24	9.33	3.29
Left lower limb	1.18	0.49	11.42	1.30	9.33	3.27
Trunk (trunk + head)	3.15	1.01	24.73	2.45	11.45	3.48
Whole body	6.25	1.99	57.85	5.02	9.75	2.89

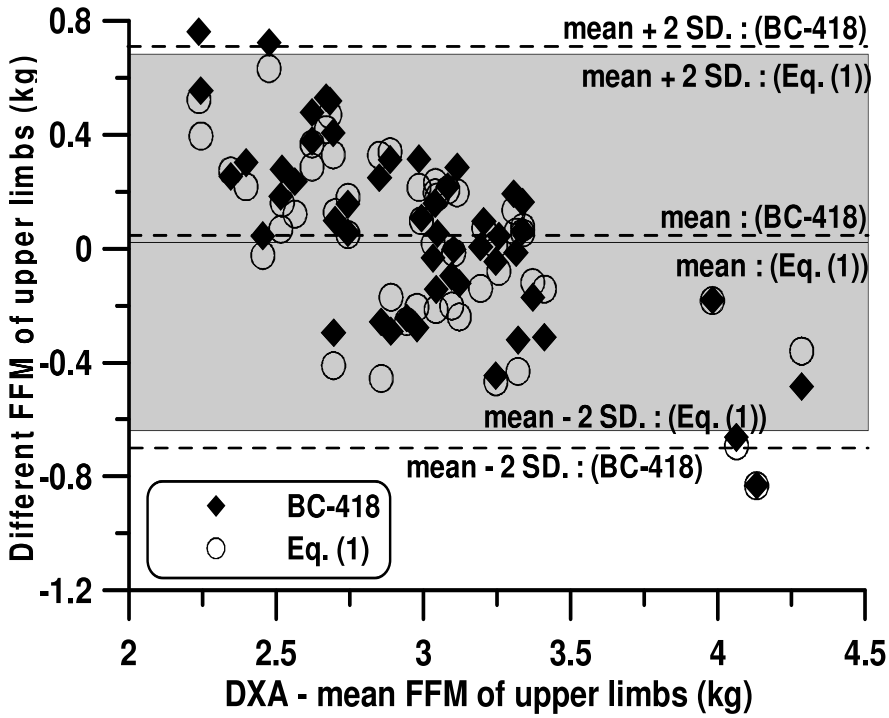

Figure 1. The relationship of range by two times standard deviation between two different BIA equation and DXA on upper limb. The "BC-418" and "Eq. (1)" on the figure represent the $FFM_{upper\text{-}limb}$ data set from BC-418 and newly developed prediction equation (PEq.), respectively. The $FFM_{upper\text{-}limb}$ mean value estimated by BC-418 and Eq. (1) were 0.061 and 0.027 kg, respectively. The range of two times standard deviation was from -0.593 to 0.714 kg on "BC-418". The range of two times standard deviation was from -0.581 to 0.635 kg on "Equation 1".

carefully determine the variability and distributions between FFM estimated by the aforementioned correlation equations vs. FFM values measured by DXA (Figures 1 to 4).

DISCUSSION

Both of the correlation coefficients of whole body FFM between measured by DXA and by BC-418 and that between PEq. were shown highly correlation. However, all the correlation coefficients of each limb or trunk FFM measured by DXA between PEq. were higher than that between BC-418 measurement. The PEq. was more accurate than BC-418 athlete mode for evaluating body composition of Taiwan elite football players. We could determine the variability and distributions between upper limb FFM estimated by PEq. vs. by DXA after surveying program adopted by Bland and Altman (Figure 1). The upper limb FFM estimated by both BC-418 and that of PEq. showed that they were overestimated. Namely, the FFM was underestimated compared with gold standard DXA. The same results of overestimated FFM were also shown in Figure 2. In addition, the deviation of both the upper limb FFM (Figure 1) and lower limb FFM (Figure 2) by BC-418 measurement was larger than that of PEq. measurement. The similar results can also be observed (Bell et al., 2000). In general, the performance of football players depends on speed, skill and tactics. The elite football players with power, speed and agility always have relatively low FFM. Meanwhile, brief, intense bursts of power depend partly on muscle size, so this type of activity may favor athletes with greater muscle mass or FFM. The BF measured by DXA in Taiwan elite football players was 9.75%, which are similar to other measurement as 10% (Shephard, 1997), 10.0 to 10.8% (Davis et al., 1992) and 12.1% (Wittich et al., 2001). There was different BF in various body segments. In this study, the upper limb fat, lower limb fat, truck fat and total BF on Taiwan elite football players were 5.18, 9.33, 11.45 and 9.75%, respectively. It was normally not only on general people but on elite football players that the upper limb BF was less than the lower limb BF. Obviously, the information was upgraded on evaluating nutrition status and training load while evaluating athlete BF used each body segment instead of whole body only.

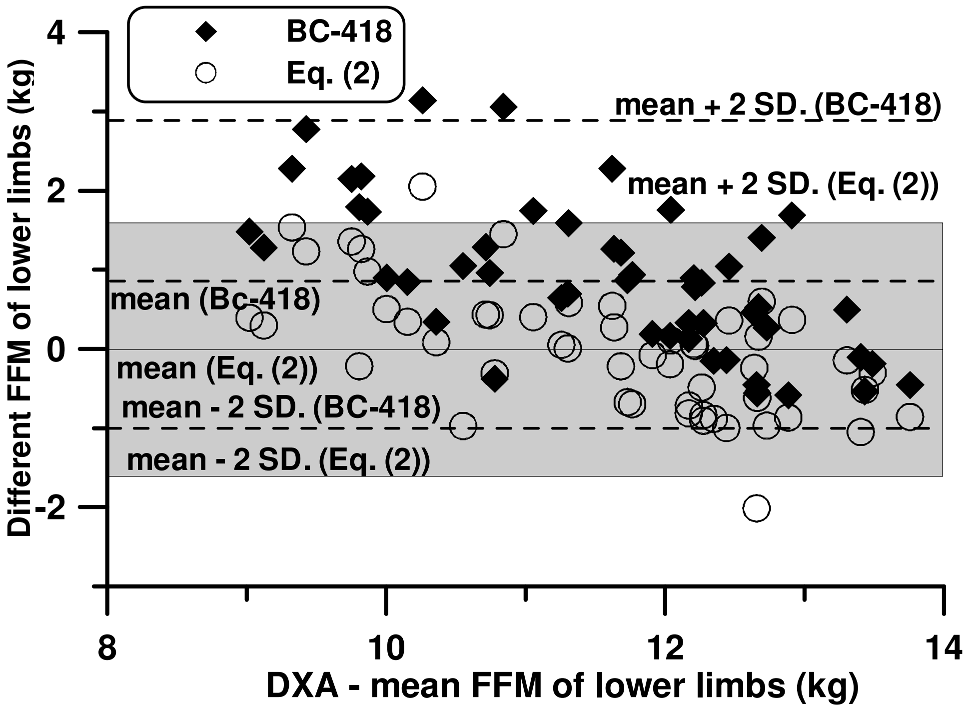

Figure 2. The relationship of range by two times standard deviation between two different BIA equation and DXA on lower limb. The “BC-418” and “Eq. (2)” on the figure represent the $FFM_{lower\text{-}limb}$ data set from BC-418 and newly developed prediction equation (PEq.), respectively. The $FFM_{lower\text{-}limb}$ mean value estimated by BC-418 and Eq. (2) were 0.895 and -0.014 kg, respectively. The range of two times standard deviation was from -0.994 to 2.783 kg on “BC-418”. The range of two times standard deviation was from -1.607 to 1.579 kg on “Eq. (2).

In the other study of Sato (Sato et al., 2007), the validation of accuracy of BC-118 (Tanita Corp, Tokyo, Japan) by using DXA measurement of obesity subjects has shown that correlation coefficients of whole body, trunk, lower limb and upper limb were 0.87, 0.76, 0.86 and 0.83, respectively, which are similar as the present data. All the correlation coefficients of $FFM_{upper\text{-}limb}$, $FFM_{lower\text{-}limb}$ and FFM_{whole} measured by DXA between that of PEq. were higher than that of BC-418 measurement (Table 4). The FFM_{trunk} derived by the FFM_{whole} excepting both $FFM_{upper\text{-}limb}$ and $FFM_{lower\text{-}limb}$ was shown in Equation 4. The deviation of measurement of FFM_{trunk} by PEq. was smaller than Tanita measurement (Figure 3). Either higher or lower counts of fat mass may be evaluated by BIA than by the independent of true fat content of the individual from DXA; therefore, body composition results assessed by a BIA in elite male athletes should be interpreted with caution, especially in individual subjects (Svantesson et al., 2008). In this study, our newly developed equations for estimating body composition were specific to the football players.

Conclusions

All the correlation coefficients between measurement of

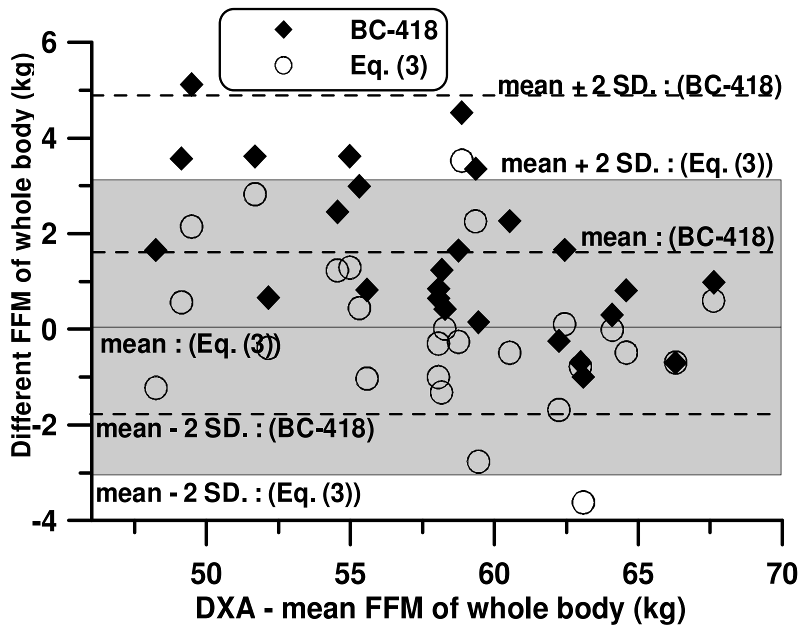

Figure 3. The relationship of range by two times standard deviation between two different BIA equation and DXA on whole body. The "BC-418" and "Equation (3)" on the figure represent the $FFM_{whole\ body}$ data set from BC-418 and newly developed prediction equation (PEq.), respectively. The $FFM_{whole\ body}$ mean value estimated by BC-418 and Eq. (3) were 1.568 and -0.042 kg, respectively. The range of two times standard deviation was from -1.757 to 4.892 kg on "BC-418". The range of two times standard deviation was from -3.265 to 3.182 kg on "Equation (3)".

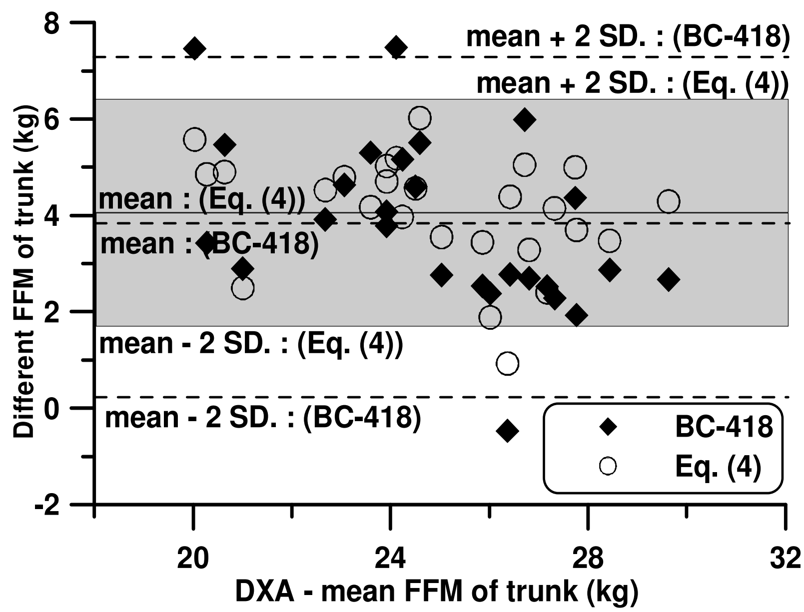

Figure 4. The relationship of range by two times standard deviation between two different BIA equation and DXA on trunk. The "BC-418" and "Equation (4)" on the figure represent the FFM_{trunk} data set from BC-418 and newly developed prediction equation (PEq.), respectively. The FFM_{trunk} mean value estimated by BC-418 and Eq. (4) were 3.808 and 4.088 kg, respectively. The range of two

times standard deviation was from 0.253 to 7.368 kg on “BC-418”. The range of two times standard deviation was from 1.736 to 6.440 kg on “Equation (4)”.

Table 4. The measured fat free mass of slope, intercept, standard deviation (SD.) and correlation coefficient (R) between DXA and BC-418 by our newly developed prediction equation.

	Slope	Intercept	SD.	R
		BC-418		
$FFM_{upper\text{-}limb\ (BC418)}$	0.44	1.72	0.33	0.69
$FFM_{lower\text{-}limb(BC418)}$	0.49	6.70	0.94	0.67
$FFM_{trunk(BC418)}$	0.66	12.17	1.78	0.74
$FFM_{whole(BC418)}$	0.81	12.62	1.66	0.95
		Newly developed prediction equation		
$FFM_{upper\text{-}limb}$	0.52	1.46	0.30	0.75
$FFM_{lower\text{-}limb}$	0.57	4.85	0.80	0.76
FFM_{trunk}	0.85	7.67	1.17	0.89
FFM_{whole}	0.90	5.43	1.61	0.95

fat mass in each limb or trunk by DXA and by our newly developed predictive equation were higher than Tanita BC-418 measurement. Meanwhile, both of the lower deviation of measurement of fat free mass and higher correlation coefficients in our newly developed predictive equation has shown the feasible application in monitoring the fat free mass in athletes.

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