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BRIEF REPORT

Association of the body adiposity index (BAI) with metabolic risk factors in young and older overweight and obese women

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Abstract
Purpose Body adiposity index (BAI) is a novel index for the assessment of percentage fat mass (FM%). We tested the association between BAI and metabolic outcomes in overweight and obese women of different ages.
Methods 260 young women (24.7 ± 5.3 years, 31.0 ± 5.0 kg/m^2) and 328 older women (66.9 ± 4.6 years, 34.8 ± 4.7 kg/m^2) were recruited. BAI was calculated using hip circumference and height. Bioimpedance analysis was used to measure FM%. Metabolic risk was assessed using a composite z score integrating standardised measurements of fasting glucose, total cholesterol, liver enzymes and triglycerides.
Results The association between BAI and FM% was modest in both young ($r = 0.56$, $p < 0.001$) and older ($r = 0.49$, $p < 0.001$) groups. BAI was directly associated with metabolic risk in young women ($r = 0.29$, $p < 0.001$), whereas it showed a weak, inverse association in the older group ($r = -0.14$, $p = 0.01$).
Conclusions BAI validity needs to be re-assessed in older individuals for better definition of its predictive accuracy.

Keywords Obesity · Body composition · Fat mass · Metabolic risk · Ageing

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Introduction

Body mass index (BMI) represents the most widely and epidemiologically used marker of excess adiposity. Nonetheless, BMI is known to be of limited accuracy, being also different for males and females with similar percent body adiposity [1].

Although direct assessments of body composition would be ideal for accurate measures of adiposity, such tools are not readily available in clinical and epidemiological settings. As such, identifying the predictive value of surrogate measures of adiposity in relation to health outcomes is needed.

Recently, the body adiposity index (BAI) has been proposed as an alternative parameter for the estimation of fat mass percentage (FM%). The BAI originally proposed by Bergman et al. [1] ($BAI_{Bergman}$) is calculated as the ratio between hip circumference and height, and has been used to measure adiposity and as a predictor of cardio-metabolic risk [1–4]. The $BAI_{Bergman}$ was initially validated in Hispanic and African-American populations against FM% measured by dual energy X-ray absorptiometry (DXA) [1, 2]. In addition to being an easy, non-invasive and low-cost technique, the $BAI_{Bergman}$ has advantages over BMI since it does not require measurements of body weight (more portable), and importantly, the relationship between hip circumference and height is independent and has a stronger correlation with FM% [2].

Although several studies have investigated the association between BAI and health outcomes, some inconsistent results on the advantages of BAI over standard anthropometric measurements highlight the need for further research [5]. A number of studies have not been able to support the validity of BAI in selected cohorts of individuals, and have also reported a weaker association with metabolic risk factors as compared to BMI and waist circumference (WC) [4, 6–11].

Subsequently, an attempt was made to modify the $BAI_{Bergman}$ algorithm [1, 2], after validation in a Caucasian population, using data from the Fels longitudinal study (BAI_{Fels}) [7]. Nonetheless, the association of both BAI algorithms with metabolic risk remained inferior as compared to BMI and WC [7].

Noticeably, most of the studies investigating the association between BAI and health outcomes were conducted in young and middle-aged subjects or in elderly subjects with chronic disease (kidney failure) [12] raising questions regarding the generalizability of the BAI index validity in older aged populations.

The aim of this study was to evaluate the association between the BAI ($BAI_{Bergman}$ [1, 2], BAI_{Fels} [7]) with established markers of metabolic risk including fasting glucose, total cholesterol, liver enzymes, triglycerides, in young (age 18–42 years) and older (age 60–83 years) overweight and obese women from a clinical population in southern Italy. Our secondary aim was to investigate the association of both BAI indexes with anthropometric adiposity indexes (BMI, WC) and body composition measures (FM%). Our hypothesis was that BAI would predict metabolic risk in both young and older individuals, showing a strong association with FM%.

Methods

The study was conducted at the weight loss clinic of the Department of Neuroscience, Section of Physiology and Nutrition of the University of Naples "Federico II", Southern Italy. The Research and Ethics Committee of the Department of Neuroscience of the University of Naples "Federico II" approved the project. All subjects provided written informed consent.

Subjects

Young cohort

Two hundred and sixty consecutive young overweight and obese adult women (age range 18–42 years) attending a weight loss clinic between January 2008 and December 2011 were included in a study exploring the sources of variability in body composition and metabolism [13]. Exclusion criteria included: pregnancy and breastfeeding, cancer or medication use that may have influenced body weight regulation. Patients with thyroid disorders on a stable thyroid replacement therapy, dyslipidaemia and hypertension were included, as were those with type 2 diabetes unless on insulin therapy.

Older cohort

Three hundred and twenty-eight consecutive overweight and obese older women (age range 60–83 years) attending an outpatient nutritional clinic for older subjects between January 2008 and December 2011 were included in the study. Similarly, subjects were excluded if they reported a history of disease or taking prescribed medications interfering with body weight. Patients with thyroid disorders on a stable thyroid replacement therapy, dyslipidaemia and hypertension were included, as were those with type 2 diabetes unless on insulin therapy.

Measurements

Anthropometry

Standing height, weight and waist circumference were measured with subjects wearing light clothing. The BMI, $BAI_{Bergman}$ and BAI_{Fels} were computed according to specific algorithms, which take the following form:

$$\text{BMI } \left(\text{kg/m}^2\right): \frac{\text{weight (kg)}}{\text{height (m)}^2}$$

$$\text{BAI}_{\text{Bergman}} \text{ (FM\%) [1, 2]: } \frac{\text{(hip circumference (cm))}}{\text{height (m)}^{1.5}} - 18$$

$$\text{BAI}_{\text{Fels}}\text{(FM\%) [7]: } 1.26 \times \frac{\text{(hip circumference (cm))}}{\text{height (m)}^{1.4}} - 32.85$$

Bioimpedance analysis

Bioimpedance measurements (BIA-101, RJL/Akern Systems, Clinton Township, MI, USA) were conducted according to standardised protocols to measure FFM and FM, using the manufacturer's equations. Briefly, the measurement protocol required subjects to lie supine on a bed with arm and legs open to create a 45° angle. Electrodes were then attached to specific anatomical landmarks on the wrist and ankle areas of the non-dominant side for the measurement of the electrical resistance measured as the drop in voltage between the electrodes injecting the small alternate electrical current and the electrodes measuring the intensity of the current. Body composition data were

adjusted for height to calculate the fat mass index (FMI = FM divided by height^2) and fat-free mass index (FFMI = FFM divided by height^2) [14].

Clinical biochemistry

Each patient was invited to have 8-h fasting biochemical tests at their local hospital or clinical biochemistry service and these results were collected at the first appointment. The biochemical tests included in the analysis are: alanine and aspartate amino-transferases, total cholesterol, triglycerides and fasting plasma glucose. A continuous metabolic risk z score was computed as the average of the z scores for the individual traits, to evaluate differences in risk between the two age groups [15]. The risk z score was calculated using data on alanine amino-transferase (ALT), aspartate amino-transferase (AST), total cholesterol, triglycerides and fasting plasma glucose. For each of these variables, a z score was computed as the number of SD units from the sample mean after normalisation of the variables, i.e., z = ([value − mean]/SD).

Statistical analysis

Continuous variables were described using summary statistics. Student's t test for independent samples was used to detect differences between age groups (young versus old). Analysis of covariance was also performed to test whether differences in metabolic risk z score between the two groups were explained by age, BMI, WC, BAI, FMI and FFMI. A paired t test was used to evaluate differences between the two BAI measures ($BAI_{Bergman}$ and BAI_{Fels}).

Correlation analysis among anthropometric adiposity indexes, FM%, metabolic outcomes and derived metabolic risk z score was performed for each age group. Multiple linear regression was used to test the association between BAI and metabolic risk z score for each age group. Three models were built in order to evaluate the association between BAI and metabolic risk (BAI + age; Model 1) and after adjustment for anthropometric (Model 1 + BMI + WC; Model 2) and body composition variables (Model 2 + FMI + FFMI; Model 3).

SPSS 17 software (SPSS for Windows, SPSS Inc, USA) was used for the statistical analysis. The significance cut-off value was taken at 0.05.

Results

Descriptive statistics

Older women had a significantly higher average BMI ($\Delta = +3.7$ kg/m^2, $p < 0.001$) and WC ($\Delta = 16.6$ cm, $p < 0.001$) than young women. The two groups were not different for body weight or hip circumference and the difference in BMI was essentially linked to the significantly shorter stature of older women ($\Delta = -7.2$ cm, $p < 0.001$). Fat mass was higher in older subjects before ($\Delta_{FM} = +6.2$ kg, $p < 0.001$) and after adjustment for height ($\Delta_{FMI} = +3.8$ kg/m^2, $p < 0.001$), whereas the difference in FFM between the two groups disappeared after age-adjustment (FFMI, $p = 0.33$).

Both BAI measures were significantly higher in older subjects and BAI_{Fels} estimates were significantly greater than $BAI_{Bergman}$ in both young ($\Delta = +2.8$, $p < 0.001$) and older ($\Delta = +3.7$, $p < 0.001$) women (Table 1). The analysis of the metabolic parameters showed significant differences between young and older women for total cholesterol, triglycerides, glucose, liver enzymes (ALT, AST) and metabolic risk z score (Table 1).

Correlation analysis

Since the association among the two BAI measures and other indexes of adiposity and metabolic factors was comparable,

Table 1 Body composition and metabolic characteristics of young and old overweight and obese women

	Young ($N = 260$)		Old ($N = 328$)		p
	Mean	SD	Mean	SD	
Age (years)	24.7	5.3	66.9	4.6	<0.001
Weight (kg)	80.3	14.5	81.7	12.3	0.16
Height (cm)	160.6	6.0	153.3	6.4	<0.001
Body mass index (kg/m^2)	31.0	5.0	34.8	4.7	<0.001
Waist circumference (cm)	89.1	12.1	105.7	11.2	<0.001
Hip circumference (cm)	111.9	10.5	112.2	9.6	0.66
Fat mass (kg)	30.7	10.1	36.9	8.3	<0.001
Fat-free mass (kg)	49.6	5.8	44.8	5.8	<0.001
Fat mass (%)	37.4	6.2	44.7	4.3	<0.001
Fat-free mass (%)	62.5	6.2	55.2	4.3	<0.001
Fat mass index (kg/m^2)	11.8	3.6	15.7	3.3	<0.001
Fat-free mass index (kg/m^2)	19.2	1.9	19.0	2.0	0.32
Body adiposity index$_{Bergman}$	37.0	5.2	41.2	6.0	<0.001
Body adiposity index$_{Fels}$	39.8	6.8	45.0	7.7	<0.001
Total cholesterol (mg/dL)	177.4	32.9	214.6	41.8	<0.001
Triglycerides (mg/dL)	89.9	51.3	133.1	55.8	<0.001
Glucose (mg/dL)	85.0	11.0	102.7	23.2	<0.001
AST (IU/L)	19.2	7.1	24.9	18.3	<0.001
ALT (IU/L)	21.1	15.5	25.8	15.0	<0.001
Metabolic risk z score	−1.7	2.2	1.4	2.8	<0.001

Body adiposity index: unit not specified as calculated as ratio between hip circumference and height (see "Methods"). The calculation of the metabolic risk z score is described in the "Methods" section

N number of subjects, *AST* aspartate amino transferase, *ALT* alanine amino transferase

only results for the $BAI_{Bergman}$ were reported (Table 2). The association between BAI and BMI was stronger than the association between WC and FM% and correlations values were consistently higher in younger women. The BAI showed a pronounced age-interaction since a direct association was found with most metabolic risk factors in young women, whereas the direction of the association was reversed in older women. BMI and WC were directly associated with most of the metabolic risk factors in young women whereas the only factors associated with BMI and WC in older women were AST ($r = 0.12$, $p = 0.02$) and glucose ($r = 0.13$, $p = 0.02$) (Table 2).

Multiple linear regression

The association of BAI with metabolic risk z score was immediately removed in young women by adding BMI ($p = 0.006$) to the model, whereas both BMI ($p < 0.001$) and BAI ($p < 0.001$) were associated with metabolic risk in older women (Model 1). The addition of WC removed the effect of BMI in young women but not in older women (Model 2). The role of central adiposity (WC) as a risk factor for metabolic risk remained in young women ($p = 0.03$) after entering body composition variables to the model (FMI, FFMI) whereas the protective role of BAI for metabolic risk was substantiated in older women ($B \pm SE = -0.16 \pm 0.03$, $p < 0.001$) (Model 3) (Table 3).

Discussion

The association between the BAI with commonly applied clinical outcomes of metabolic health varied in a clinical population of young and older women. In line with previous results [6–11], the BAI was not associated with any metabolic outcomes in young women. In contrast, higher BAI values seemed to be associated with a better metabolic profile in older women. The protective effect of the BAI on the cumulative metabolic risk in the older aged group was not removed when the model was fully adjusted by adiposity (BMI, WC, FMI) and fat-free mass (FFMI). Therefore, our findings raise the question whether the BAI is a useful indicator of metabolic risk in the older aged population.

We had initially conjectured that the validation of the BAI in a Hispanic and African-American population ($BAI_{Bergman}$) [1, 2] could amplify the misclassification bias in our analyses, whereas the optimization of the BAI formula from a Caucasian sample (BAI_{Fels}) [7] could have resolved such methodological bias. However, the two BAI measures produced essentially equivalent results in the prediction of metabolic risk for both young and older subjects. However, the BAI_{Fels} produced significantly greater values than the $BAI_{Bergman}$ in the assessment of adiposity, and the agreement with FM% was dependent on age. Furthermore, the $BAI_{Bergman}$ was associated with FM% in young women whereas in the older group a stronger association with FM% was observed with the updated index (BAI_{Fels}). The interpretation of these results is difficult since our study has relied on measures of bioimpedance analysis for the assessment of body composition, rather than DXA, which gives a more refined assessment. Further studies using more accurate body composition methods (DXA, 4-compartment models) evaluating the agreement between BAI and FM% in ageing populations are needed.

Table 2 Correlation between adiposity indexes and their association with metabolic outcomes in young and old overweight and obese women

	$BAI_{Bergman}$		BAI_{Fels}		Body mass index (kg/m^2)		Waist circumference (cm)		Fat mass (%)	
	Young	Old	Young	Old	Young	Old	Young	Old	Young	Old
Body mass index (kg/m^2)	0.81**	0.69**	0.82**	0.70**	–	–	–	–	–	–
Waist circumference (cm)	0.57**	0.40**	0.59**	0.42**	0.85**	0.78**	–	–	–	–
Fat mass (%)	0.56**	0.49**	0.58**	−0.50**	0.71**	0.67**	0.65**	0.58**	–	–
Total cholesterol (mg/dL)	0.04	−0.10*	0.04	−0.11*	0.07	−0.12*	0.10	−0.08	0.02	−0.05
Triglycerides (mg/dL)	0.23**	−0.18**	0.24**	−0.18*	0.30**	−0.02	0.32**	0.06	0.16*	−0.05
Glucose (mg/dL)	0.15*	−0.05	0.15*	−0.05	0.14*	0.07	0.13*	0.13*	0.13*	−0.04
AST (IU/L)	0.14*	0.006	0.15*	0.005	0.12*	0.12*	0.10	0.05	0.09	0.03
ALT (IU/L)	0.24**	−0.06	0.25**	−0.05	0.27**	0.09	0.26**	0.05	0.19*	0.06
Metabolic risk z score	0.29**	−0.14*	0.29**	−0.14*	0.32**	0.06	0.33**	0.08	0.20**	0.01

Body adiposity index: calculated as ratio between hip circumference and height (see "Methods"). The calculation of the metabolic risk z score is described in the "Methods" section

AST aspartate amino transferase, *ALT* alanine amino transferase

* $p < 0.05$; ** $p < 0.01$

Table 3 Multiple regression analysis to evaluate the association between anthropometric and body composition measurements with a cumulative metabolic risk *z* score (dependent variable) in young and old overweight and obese women

Group models	Young ($N = 260$)				Old ($N = 328$)			
	B	SE	*t*	*p* value	*B*	SE	*t*	*p* value
Model 1								
R^2 (F)	0.11 (15.6)			<0.001	0.07 (7.9)			<0.001
$BAI_{Bergman}$	0.02	0.04	0.52	0.60	**−0.16**	**0.03**	**−4.71**	**<0.001**
BMI (kg/m^2)	**0.12**	**0.04**	**2.79**	**0.006**	**0.18**	**0.04**	**4.12**	**<0.001**
Model 2								
R^2 (F)	0.12 (12.2)			<0.001	0.07 (8.0)			<0.001
$BAI_{Bergman}$	0.06	0.04	1.31	0.19	**−0.17**	**0.03**	**−4.65**	**<0.001**
BMI (kg/m^2)	0.006	0.07	0.06	0.94	**0.21**	**0.07**	**2.99**	**0.003**
WC (cm)	**0.04**	**0.02**	**2.21**	**0.02**	−0.01	0.02	−0.46	0.64
Model 3								
R^2 (F)	0.13 (7.6)			<0.001	0.08 (5.7)			<0.001
$BAI_{Bergman}$	−0.06	0.04	1.37	0.17	**−0.17**	**0.03**	**−4.58**	**<0.001**
BMI (kg/m^2)	0.53	0.68	0.79	0.42	0.01	0.18	0.07	0.94
WC (cm)	**0.05**	**0.02**	**2.36**	**0.01**	−0.006	0.02	−0.28	0.77
FMI (kg/m^2)	−0.59	0.67	−0.88	0.37	0.13	0.20	0.64	0.52
FFMI (kg/m^2)	−0.46	0.68	−0.68	0.48	0.29	0.16	1.82	0.06

Significant predictors are highlighted in bold

N number of subjects, *BMI* body mass index, *WC* waist circumference, *HC* hip circumference, *BAI* body adiposity index, *FFMI* fat-free mass index, *FMI* fat mass index

The association of the BAI with FM% measured by DXA has been investigated in several studies, with mixed findings. Johnson et al. [7] found that the BAI was more strongly associated with FM% than BMI but the agreement was still poor at lower levels of FM%. Two clinical studies tested the performance of the BAI in lipodystrophic subjects [16] and older subjects (mean age 64 years) with chronic kidney failure [12] and both found that BAI was more closely associated with adiposity as compared to BMI. However, other studies reported poor associations of the BAI with FM% in severe obese women [17] and inaccuracy in the index for measuring changes in FM% over a period of 1 year in middle-aged women (SWAN cohort) [18].

The results of the association between the BAI and cardio-metabolic risk are unconvincing and favour the use of BMI and WC. In particular, WC provides an indirect assessment of centralised adipose tissue accumulation, which is closely linked to visceral fat depots and to the pathogenesis of metabolic disorders such as insulin resistance and endothelial dysfunction [8]. In the FATE cohort, BAI did not emerge as a predictor of vascular health in multiple regression models including other anthropometric and body composition measures [19]. The SAPHIR study showed that BAI and BMI were both weakly associated with glucose, lipids and blood pressure in 1,770 male and female between 40 and 70 years of age [4]. The Bogalusa study reported that BAI was a poorer predictor than BMI and WC of blood pressure, lipid, insulin and glucose levels in analyses stratified by age, gender, ethnicity and BMI categories [9]. The predictive value of the BAI for type 2 diabetes was recently tested in two large longitudinal studies: the European Prospective Investigation into Cancer and Nutrition (EPIC)-Potsdam study (9,729 men, 15,438 women) and the Cooperative Health Research in the Region of Augsburg (KORA) study (5,573 men, 5,628 women). The results showed that WC in men and hip circumference in women were better predictors of FM% than BAI and BMI. BAI was not as strong a predictor of diabetes as BMI, while waist circumference was the strongest predictor in both cohorts [11].

An important limitation of the study is the cross-sectional design, which restricts the interpretation of the associations between body composition variables and metabolic risk factors. The analyses are based on a clinically representative population and results need to be interpreted with caution as they may not generalise to other populations. Also the blood biochemistry data were obtained from different biochemistry analytical laboratories. However, this would be expected to introduce random bias in the current analysis, and to decrease the statistical power for detecting significant differences. Finally, the measurement error associated with bioimpedance analysis may have influenced the associations

between BAI and the anthropometric adiposity indexes and estimates of FM.

Conclusions

Our study contributes to the growing literature on BAI, showing that, in line with previous results, the poor accuracy of BAI as an index of adiposity in young individuals was observed. However, in older overweight and obese women a paradoxical association of BAI with metabolic risk was reported, suggesting that the validity and the predictive value of this novel adiposity index may need to be re-evaluated in older individuals in order to define the predictive accuracy for the assessment of body adiposity.

Acknowledgments MS collected the data (young cohort), designed the analysis, co-analysed the data and wrote the manuscript. CMP and SB co-analysed the data and revised the manuscript. JL advised on the statistical analysis and revised the manuscript. NG and EM collected the data (old cohort) and revised the manuscript. AC designed the study and revised the manuscript. All authors read and approved the findings of the study.

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Conflict of interest All authors have no conflicts of interest to declare.

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