ORIGINAL ARTICLE

The interaction effect of body mass index and age on fat-free mass, waist-to-hip ratio, and soft lean mass

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Background: Research has shown that body mass index (BMI) does not take into consideration the gender and ethnicity. The primary purpose of this study was to examine the interaction effect of the BMI and age on fat-free mass (FFM), waist-to-hip ratio (WHR), and soft lean mass (SLM). The secondary purpose was to evaluate the practical significance of the findings by examining effect sizes. **Materials and Methods:** The study was comparative in nature and employed a factorial design. Due to nonexperimental nature of the investigation, no causal inferences were drawn. The nonprobability sample consisted of 19,356 adults. Analysis of the data included factorial analysis of variance, analysis of simple effects, calculation of mean difference effect sizes, and data transformation. The Statistical Package for the Social Sciences version 22 was employed for the purpose of data manipulation and analysis. **Results:** The BMI by age interaction effects on FFM, $F(10, 19{,}338) = 28.26$, $P < 0.01$, on WHR, $F(10, 19{,}338) = 18.46$, $P < 0.01$, and on SLM, $F(10, 19{,}338) = 14.65$, $P < 0.01$, was statistically significant and ordinal in nature. Analysis of the effect sizes, ranging from 0.30 to 1.20, showed that the BMI and age influenced the WHR but their interaction effects on FFM and SLM, ranging from 0.04 to 0.36 and 0.03 to 0.33, respectively, were mainly negligible. **Conclusion:** Based on the examination of the statistical and practical significance of the results, it is concluded that the BMI and age together can influence the WHR but their interaction effect on the FFM and SLM is questionable.

Key words: Body composition, body fat distribution, body mass index, body weight, waist-to-hip ratio

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INTRODUCTION

In many epidemiological studies, the body mass index (BMI) is an indicator of the presence of overweightedness and obesity in adolescents.[1-3] The BMI can predict body density, proportions of fat, and fat-free mass (FFM). The literature suggests that the BMI is well correlated with the percentage of body fat (PBF) and is a good indicator of risks associated with various diseases.[1,2] However, there are researchers who have questioned the adequacy of the BMI in accurately measuring body fitness indices such as the PBF and FFM.[4]

The PBF and FFM are instrumental in evaluating the degree of human obesity. Human health requires reasonable PBF as too much or too little body fat will induce various diseases.[5] The PBF may remain constant with age, but aging is associated with substantial redistribution of fat tissue among depots.[6] Also of interest are variations in body fat distribution that may affect all populations, for example, variations between men and women, and with aging.[7] After adjusting for differences in height, men have larger total lean mass (soft lean mass [SLM] + mineral) and lower fat mass than women have. Changes in body weight and BMI are strongly related to FFM and explain 54% of the variance in those changes.[8] It is noted that the BMI does not take into consideration the

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differences between men and women and that it cannot be generalized to various ethnic groups. In addition, it is shown to be inaccurate among athletes who are high in SLM.[9] Therefore, the measurement of the PBF and the FFM is more appropriate than the BMI in assessing obesity.[10]

The waist-to-hip ratio (WHR) is another indicator or measurement of obesity. Commonly used cutoff points for the WHR are based on studies conducted with Europeans.[11] The World Health Organization defined abdominal obesity as a WHR above 0.90 for males and above 0.85 for females or the BMI of >30.00.[12] Waist circumference increases with age, and it is larger in old people than in younger men and women.[13] Similarly, Forbes reported age-related differences in WHR in all BMI categories in both sexes. He found that changes in waist and hip circumferences correlated directly with changes in weight but differently among men and women.[8]

Measurements such as body weight, BMI, and WHR do not reflect the FFM, PBF, or SLM; as a result, scientists have developed other methods to estimate body composition, namely, magnetic resonance imaging, dual-energy absorptiometry, and bioelectrical impedance analysis (BIA).[14] Our review of the literature showed that the interaction effect of the BMI and age on various body composition indices, which has clinical implications, had not been investigated. Since it is important to know at what age group BMI may affect FFM, WHR, and SLM, we examined the interaction effects of the BMI and age on the FFM, WHR, and SLM, using the BIA. To better understand the statistically significant findings, mean difference effect sizes were examined to evaluate the practical significance of the findings.

MATERIALS AND METHODS

The permission to conduct the study was obtained from the Ethics Committee at Hormozgan University of Medical Science on May 6, 2009 (office of the vice-chancellor for research and technology, #6-HEC-88-2-16). The setting was a health and diet therapy center at Hormozgan University of Medical Sciences in Bandar Abbas, Iran. The nonexperimental study was comparative in nature, took place between 2009 and 2014, and employed a factorial design.

We had recruited 23,300 individuals who voluntarily agreed to participate in the study. In accordance with the approved protocol, those who were not at least 20 years old, had pacemakers, were pregnant, and had been hospitalized for at least 3 months before entering the study were excluded from the study. There were 19,356 adults who met the inclusion criteria and gave us the permission to use their data for the purpose of the study.

The BIA was performed using a body composition analysis device - Plusavis 333. This device uses the frequency range between 50 and 250 kHz and utilizes the method of direct segmental multi-frequency BIA. This method enabled us to measure the study variables of interest, namely, FFM, WHR, and SLM. Whole-body impedance measurements were taken using the standard positions of outer and inner electrodes on the right hand and foot.[15] The device was explained to research participants. Trained technicians were in-charge of all measurements. The height in centimeters was measured to the nearest 0.50 cm by a stadiometer. Weight (kg) was divided by squared height (cm^2) to measure the BMI.

We categorized the sample into six groups based on the BMI, namely, (1) underweight (under 18.50), (2) normal weight (18.50–24.99), (3) overweight (25.00–29.99), (4) moderately obese (30.00–34.99), (5) severely obese (35.00–39.99), and (6) very severely obese[16] (40.00 and higher).

Fat in kilograms was used to measure FFM. Circumference of waist divided by the circumference of the hip, both in meters, determined the WHR. The SLM was measured by extra muscle in kilogram.

Age in years was used to categorize the sample into three groups: (1) 20–39, (2) 40–59, and (3) 60–79. Thus, a 6 × 3 factorial design was formed.

Interaction effect

The effect of a variable on the outcome measure by itself is called the main effect. How two or more variables together affect the outcome is called an interaction effect. For example, if A and B are the variables/factors, we have a two-way factorial design in which three hypotheses are tested: (1) main effect A, (2) main effect B, and (3) interaction effect of A and B on the outcome measure. The interaction effect is either ordinal (the rank order of the levels of one independent variable does not change across levels of a second independent variable) or dis-ordinal (the rank order of the levels of one independent variable changes across levels of a second independent variable). For example, if there are two weight loss programs and men outperform women in both, the interaction effect is ordinal in nature. On the other hand, if one works better for men and the other one works better for women, we have a dis-ordinal interaction. If the interaction effect is statistically significant, analysis of simple effects is performed for the purpose of *post hoc* analysis. In this study, age and the BMI were the two independent variables; FFM, WHR, and SLM were the dependent variables.

Simple effect

Analysis of the simple effects consisted of two sets of analyses. The first set examined age at each of the six levels of BMI: (1) age at underweight, (2) age at normal weight, (3) age at overweight, (4) age at moderately obese, (5) age at severely obese, and (6) age at very severely obese. The second set examined the BMI at each of the three age groups: (1) BMI at 20–39 age group, (2) BMI at 40–59 age group, and (3) BMI at 60–79 age group. All simple effects were statistically significant at the 0.01 level.

The version 22 of the Statistical Package for the Social Sciences (SPSS) was used for the purpose of data entry, manipulation, and analysis. Descriptive statistics were used to summarize the data. A series of 6 × 3 factorial analysis of variance (ANOVA)[17] was performed to examine the main and interaction effects of the BMI and age on the FFM, WHR, and SLM. The interpretation of the results focused on the interaction effects and analysis of simple effects was performed for the purpose of *post hoc* analysis. The homogeneity of variances assumption was violated in ANOVAs. The transformation of the data included obtaining the square roots of the obtained data, which is recommended when raw data are skewed.

Mean difference effect sizes, Cohen's d, were computed to examine the practical significance of the simple effects.[18] To do so, the mean difference was divided by the pooled standard deviation and was characterized as 0.20 = small effect, 0.50 = medium effect, and 0.80 = large effect. The level of significance was set, *a priori*, at 0.01, to reduce the probability of making Type I errors due to a large sample size and performing multiple univariate tests.

RESULTS

The study participants ranged in age from 20 to 79 years; the median age was 32. The majority of the individuals were female ($n = 13684$, 70.70%). A typical individual's height and weight was 164 cm and 75.33 kg, respectively. The means and standard deviations for FFM, WHR, and SLM are summarized in Table 1, in which the negative scores indicate measures that are less than normal.

Analysis of the FFM data showed that the BMI effect was statistically significant, F (5,19338) = 4248.77, $P < 0.01$, the age effect was not statistically significant, F (2,19338) = 4.31, $P = 0.02$, and the BMI by age interaction effect was statistically significant, F (10,19338) = 28.26, $P < 0.01$. Analysis of the WHR data showed that the age effect, F (2,19338) = 1006.27, $P < 0.01$, the BMI effect, F (5,19338) = 860.50, $P < 0.01$, and the BMI by age interaction effect, F (10,19338) = 18.46, $P < 0.01$, were statistically significant. Analysis of the SLM data showed that the age effect, F (2,19338) = 56.78, $P < 0.01$, the BMI effect, F (5,19338) = 1094.26, $P < 0.01$, and the BMI by age interaction effect, F (10,19338) = 14.65, $P < 0.01$, were statistically significant.

As can be seen in Table 1, some of the standard deviations were quite large. As a matter of fact, the homogeneity of variances assumption was not met in all factorial ANOVAs. The data were transformed by obtaining their square roots, which is recommended when raw data are skewed with heterogeneous variances. All analyses were replicated, using the transformed data, and results remained the same.

As can be seen in Figure 1, all interaction effects were ordinal. In addition, all simple effects were statistically significant [Table 2].

We were not surprised by all simple effects being statistically significant because the sample sizes were large enough to detect small effects. Therefore, a detailed analysis of mean difference effects sizes [Table 3] was performed.

For the FFM, the effect sizes ranged from 0.02 to 0.36. Among the underweights, the mean difference effect size between the 40–59 and 60–79 age groups was 0.36. Among the normal weights, effect sizes were between 0.24 and 0.33. Among the overweight and moderately obese individuals, all effect sizes were less than small. Among the severely obese individuals, the only meaningful effect size was between the 20–39- and 40–59-year-olds. Among the very

Table 1: Means* and standard deviations for fat-free mass, waist-hip ratio, and soft lean mass

BMI category	Age group											
	20-39				40-59				60-79			
	n	Mean±SD			*n*	Mean±SD			*n*	Mean±SD		
		FFM	WHR	SLM		FFM	WHR	SLM		FFM	WHR	SLM
Underweight	1644	−5.1±2.1	0.7±0.1	−3.8±1.7	61	−4.2±2.3	0.3±0.1	−4.2±1.8	8	−2.9±2.4	0.8±0.1	−4.3±1.9
Normal weight	3292	0.7±2.2	0.8±0.1	−0.4±1.5	730	1.6±1.9	0.8±0.1	−0.5±1.5	94	2.4±2.1	0.9±0.1	−0.84±1.3
Overweight	4499	7.6±2.9	0.8±0.1	2.5±2.4	1950	8.0±2.9	0.9±0.1	2.3±2.5	148	8.4±3.1	0.9±0.1	1.9±2.1
Moderately obese	3016	15.1±3.2	0.9±0.1	6.2±3.9	1314	14.8±3.2	0.9±0.1	5.6±4.0	122	15.2±3.2	1.0±0.1	4.6±3.8
Severely obese	1115	22.9±4.0	0.9±0.1	11.2±5.1	569	21.8±3.5	1.0±0.1	9.4±4.8	42	21.5±3.8	1.0±0.1	8.6±5.5
Very severely obese	524	34.2±8.5	1.0±0.1	17.9±8.0	205	31.8±5.9	1.0±0.1	16.0±7.0	23	28.4±3.4	1.0±0.1	12.6±5.3

*The negative mean values indicate less than normal measures. FFM=Fat-free mass; WHR=Waist-to-hip ratio; SLM=Soft lean mass; SD=Standard deviations

Table 2: Analysis of simple effects summary table for body mass index and age interaction effect on fat-free mass, waist-to-hip ratio, and soft lean mass (*n*=19,356)

Source	df	FFM			WHR			SLM		
		SS	MS	*F*	SS	MS	*F*	SS	MS	*F*
Age										
BMI <18.5	2	290,405	145,202	6605*	57	28	11,582*	66,182	33,091	2346*
18.5 ≥BMI <25	2	179,468	89,734	4082*	24	12	4801*	30,601	15,300	1085*
25 ≥BMI <30	2	22,696	11,348	516*	9	5	1884*	4155	2078	147*
30 ≥BMI <35	2	28,003	14,001	636*	2	1	391*	9120	4561	323*
35 ≥BMI <40	2	134,395	67,197	3056*	2	1	341*	48,337	24,168	1714*
BMI ≥40	2	260,483	130,241	5924*	3	1	573*	5405	47,703	3383*
Error	19,343	425,205	21.98		48	0.01		272,780	14	
BMI (age group)										
20-39	5	1,237,561	247,512	23,643*	81	16	7259*	339,567	67,913	6141*
40-59	5	273,610	54,722	7227*	18	4	1614*	79,373	15,874	1435*
60-79	5	24,214	4842	462*	3	1	293*	7505	1501	136*
Error	19,340	202,459	10.47		43	0.01		213,870	11	

**P*<0.01. FFM=Fat-free mass; WHR=Waist-to-hip ratio; SLM=Soft lean mass; SS=Sum of square; MS=Mean square; *F*=*F*-ratio; df=Degrees of freedom; BMI=Body mass index

Table 3: Mean difference effect sizes* for fat-free mass, waist-to-hip ratio, and soft lean mass

BMI category	Age group								
	20-39 versus 40-59			20-39 versus 60-79			40-59 versus 60-79		
	FFM	WHR	SLM	FFM	WHR	SLM	FFM	WHR	SLM
Underweight	0.16	0.88	0.08	0.14	0.64	0.04	0.36	0.78	0.03
Normal weight	0.33	1.03	0.05	0.25	0.74	0.10	0.24	0.48	0.15
Overweight	0.11	1.20	0.05	0.09	0.87	0.08	0.06	0.33	0.08
Moderately obese	0.07	0.45	0.14	0.02	0.89	0.16	0.08	0.45	0.11
Severely obese	0.25	0.73	0.33	0.12	0.52	0.18	0.04	0.30	0.08
Very severely obese	0.28	0.52	0.22	0.28	0.47	0.26	0.35	0.39	0.29

*0.20=Small effect; 0.50=Medium effect; 0.80=Large effect. FFM=Fat-free mass; WHR=Waist-to-hip ratio; SLM=Soft lean mass; BMI=Body mass index

severely obese individuals, the effect sizes ranged from 0.28 to 0.35.

For the WHR, the largest difference was observed between the 20–39- and 40–59-year-old overweight individuals ($d = 1.20$), followed by the normal weight people in the same age groups ($d = 1.03$). The smallest difference was observed among severely obese subjects in 40–59 and 60–79 age groups ($d = 0.30$), followed by the overweight individuals in the same age groups.

For the SLM, between the 20–39- and 40–59-year-old age groups, the meaningful differences were among the severely obese and very severely obese individuals and (2) between the 20–39- and 60–79- and the 40–59- and 60–79-year-old age groups, all effect sizes were less than small with the exception of the very severely obese individuals.

DISCUSSION

The aim of this study was to examine the interaction effects of the BMI and age on the FFM, WHR, and SLM as well as evaluate the practical significance of the findings by examining mean difference effect size. All interaction effects were ordinal in nature and showed that the very severely obese individuals had the highest FFM, WHR, and SLM indices across all age groups, followed by severely obese, moderately obese, overweight, and normal weight individuals. Analysis of the effect sizes showed that the BMI and age influenced the WHR, but their interaction effect on FFM and SLM was questionable.

Gába and Pridalová[19] studied 2333 Czech women between the ages of 18 and 89 years and reported statistically significant increases in body fat mass (BFM) and PBFs age increased. The researchers also reported that even when FFM decreased slightly with age, body weight increased because of the increase in BFM. However, the authors did not report the practical significance of their findings. Our results were also statistically significant, but the examination of effect sizes showed the findings that were meaningful and useful in suggesting clinical implications.

All interaction and *post hoc* simple effects were statistically significant, which could have been due to large sample sizes. Thus, the discussion of the results focuses on mean difference effect sizes that are used to examine the importance of the findings.

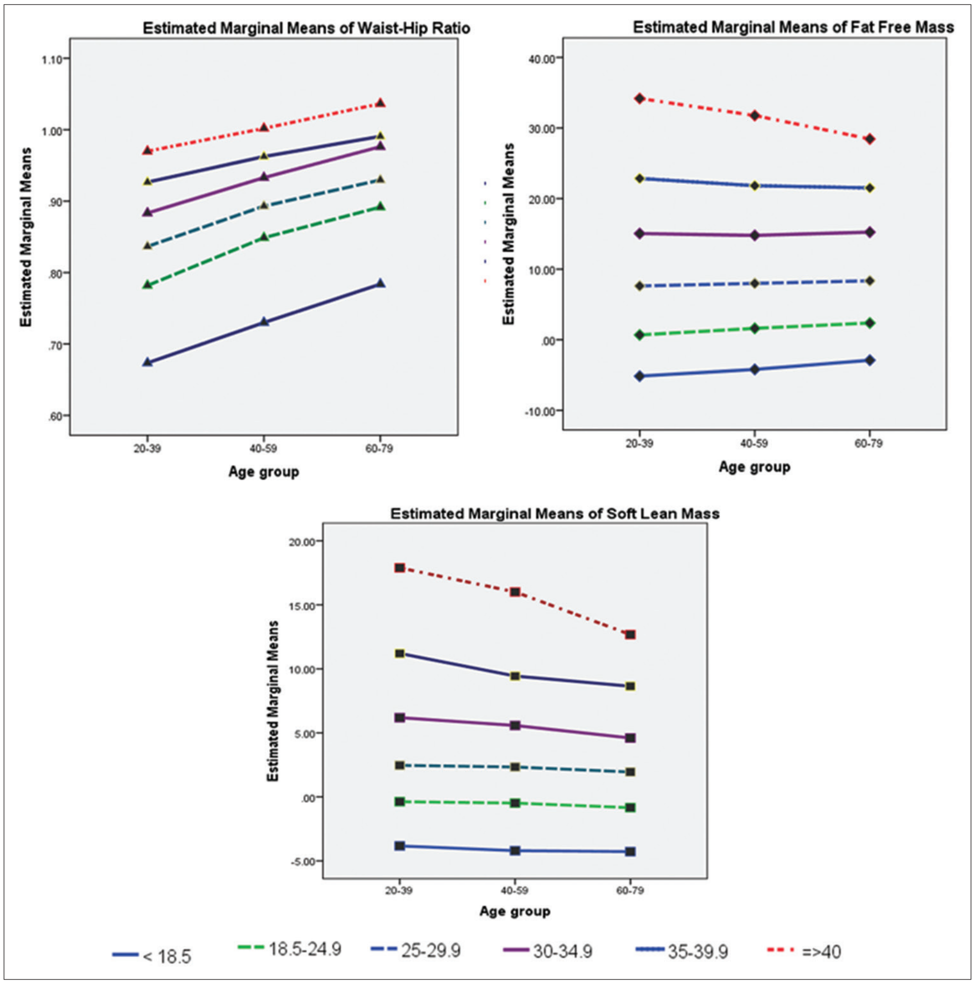

Figure 1: Ordinal interaction effects of body mass index and age on fat-free mass, waist-to-hip ratio, and soft lean mass. In all, the very severely obese had the largest measures, followed by severely obese, moderately obese, overweight, normal weight, and underweight

Among normal weight and very severely obese individuals, age differences based on the FFM were meaningful; however, they were negligible among overweight and moderately obese individuals. Among the underweights, the meaningful difference was between the 40–59- and 60–79-year-olds, while it was between the severely obese 20–39- and 40–59-year-olds. None of the effect sizes approached the cutoff point of 0.50 for medium effects. Thus, we concluded that the interaction effect of the BMI and age on the FFM is random.

Based on the WHR, all effect sizes were meaningful, ranging from 0.30 to 1.20. Consequently, we concluded that the BMI and age, together, systematically influence the WHR. Lisko *et al*.[20] reported similar findings.

Examination of the effect sizes for the SLM showed that, generally speaking, the interaction effect of the BMI and age is negligible. Very severely obese sample was the exception in which the largest difference was between 40–59- and 60–79-year-olds, followed by 20–39- versus 60–70- and 20–39- versus 40–59-year-olds.

We would like to re-emphasize the importance of examining effect sizes in drawing conclusions based on analysis and interpretation of quantitative data. This is of particular importance in studies utilizing large sample sizes, in which the presence of statistical significance can be due to the sample size. The rejection of null hypothesis does not necessarily indicate the importance of the findings. It simply means that, for example, the difference between the experimental and comparison groups is not zero. On the other hand, if the sample size is too small, results may not be statistically significant, which should not be used to quickly conclude that the findings are not important. A large sample size may result in making a Type I error (falsely rejecting a true null hypothesis, for example, concluding that the intervention works when in reality it does not). On the other hand, a Type II error (not rejecting a false null hypothesis, for example, concluding that the intervention does not work when in reality in does) is likely if the sample size is too small. The difference between the statistical significance and the practical significance must be taken into consideration in analyzing, interpreting, and reporting the results. In our study, as noted earlier, nearly all results were statistically significant, but a detailed examination of effect sizes enabled us to conclude that the BMI and age, together, systematically affected the WHR the most while their interaction effect on FFM and SLM was negligible and/or random.

Limitations

In spite of the large sample, it should be noted that the study participants were recruited from South Iran and did not represent the country's population. We recommend the replication of the study in other regions of Iran, which could enhance the generalizability of the results.

CONCLUSIONS

Based on the examination of the statistical and practical significance of the results, we conclude that the BMI and age together can influence the WHR but their interaction effect on the FFM and SLM is questionable. Thus, we highly recommend the examination of effect sizes to better understand statistically significant findings.

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Conflicts of interest

There are no conflicts of interest.

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