Original Article

The Best Obesity Indices to Use in a Single Factor Model Indicating Metabolic Syndrome: a Population Based Study

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Abstract

Objective: Although metabolic syndrome (MetS) is a major health problem worldwide, there is no universal agreement on its definition. One of the major disagreements is dealing with the issue of obesity in this definition. This study was conducted to determine a preferably better index of obesity which can be interrelated with other components of MetS in a single factor model of MetS.

Design: Out of 6140 participants of a cohort study of subjects aged 10-90 years in northern Iran, the baseline data of 5616 participants aged 18-75 was considered. Confirmatory factor analysis was conducted using AMOS software to evaluate a single factor model of MetS in which blood pressure, triglyceride (TG), high density lipoprotein (HDL), fasting blood sugar (FBS) and obesity measures including waist circumference (WC), body mass index (BMI), waist to hip ratio (WHR) and waist to height ratio (WHtR) were used as indicators of metabolic syndrome. Four single factor models differing from each other by obesity indices were evaluated. The models were evaluated in all 5616 subjects and 4931 subjects without diabetes mellitus according to sex separately.

Results: All single factor models had appropriate fit indices with CFI > 0.95, GFI > 0.95 and RMSEA < 0.08 in non-diabetic population, wherein all models obtained the best values of fit indices in men and good fit indices in women. In the general population of men, the single factor models built based on WHR (Chi-square = 6.9, df = 2, *P*-value = 0.031, RMSEA = 0.028, CI = 0.007–0.052, CFI = 0.994, GFI = 0.999 and AIC = 22.9) and WHtR (Chi-square = 9.97, df = 2, *P*-value = 0.007, RMSEA = 0.036, CI = 0.016–0.059, CFI = 0.992, GFI = 0.998 and AIC = 25.97) were fitted properly with data while in th general population of women, the model based on WHR obtained better fit indices (Chi-square = 7.5, df = 2, *P*-value = 0.023, RMSEA = 0.033, CI = 0.011–0.060, CFI = 0.994, GFI = 0.998 and AIC = 23.5). Models based on WHtR obtained better regression weights than WHR.

Conclusion: While single factor validity of MetS was confirmed in almost all models, the best models were different according to sex and population of study.

Keywords: Metabolic syndrome, obesity indices, single factor model

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Introduction

Metabolic syndrome (MetS) is of considerable importance in public health due to its association with other conditions such as cardiovascular diseases.[1,2] Although there is not a single generally accepted definition for MetS, it is often considered as a cluster of interrelated individual factors such as insulin resistance, central obesity, hypertension and dyslipidemia.[3] The fundamental disagreement on MetS definition lies in obesity indices. Although the WHO proposes body mass index (BMI) as obesity index in definition of MetS, waist circumference (WC) is utilized as obesity index in the majority of definitions. Due to absence of an agreeable definition for MetS and controversy over its mechanisms, a considerable number of studies have been conducted to recognize the causal mechanisms underlying this condition using confirmatory factor analysis methods.[4–18]

Among numerous studies, some were designed to confirm one single factor model of MetS based on insulin resistance, blood pressure, lipid profile and obesity measures while others were conducted to compare different models built on the basis of MetS components.[4–11] Meanwhile, a few evaluated different single factor models of metabolic components discriminated from each other only according to obesity indices. However, studies in this context showed inconsistent results.[8–12] The axiomatic in previous studies is their inconsistency along with obscurity of the role of ethnicity in obesity definition. The present study was conducted to evaluate a distinctive single factor model of MetS in order to determine the most appropriate obesity index to use in the definition of MetS in northern Iran.

Material and Methods

This study utilized the baseline data of a population-based cohort study in people aged 10–90 years in Amol, a northern city of Iran with more than 400,000 inhabitants. Twenty five rural and sixteen urban primary health care (PHC) centers were selected to collect the data. The population aged 10–90 years was divided into 16 strata based on sex and age groups with an interval of 10 years. Subjects were selected in each stratum according to the proportion of the associated stratum size, using simple randomization method. Sampling has been explained in details elsewhere.[19] Out

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of 6140 participants of a cohort study conducted among subjects aged 10–90 years, the baseline data of 5616 participants aged 18–75 were considered. A schematic view of the study population is shown in Figure 1.

Data collection procedure and laboratory assessment

Trained healthcare providers measured blood pressure and anthropometric data, including weight, height, waist circumference (WC) and hip circumference (HC). Before weight measurement, calibration of weighing scales was performed with 5 kg weights. Furthermore, to obtain more accurate estimations, the removal of excess clothes and shoes was recommended. Height was measured while the participants were standing against the wall with their heels and buttocks in contact with the wall. Waist circumference was determined at the midpoint between the lowest costal ridge and the upper border of the iliac crest. Each measurement of WC was repeated and if there was >2 cm discrepancy, then a third measurement was performed and the average of the two closest values was considered as WC. Hip circumference (HC) was measured at the largest circumference between waist and knee. Both WC and HC were measured with a non-stretchable and accurately calibrated scale with 0.5 cm precision.

Waist to hip ratio (WHR), waist to height ratio (WHtR) and BMI were calculated by the following equations, respectively: *WC (cm)/HC (cm), WC (cm)/ height (cm) and weight (kg)/* [*heigh (m)*]^2. Blood pressure was measured using a fitted cuff after at least five minutes of rest in a quiet room. The systolic and diastolic blood pressures (SBP and DBP) were determined as first appearance and disappearance of Korotkoff sounds, respectively. Mean arterial pressure was calculated based on the following equation:

$$MAP = DBP + \frac{1}{3}(SBP - DBP)$$

Fasting Blood Sugar (FBS) and lipid profile were assessed following at least 10 hours of fasting by the BS200 Auto analyzer (Mindray, China). Ten percent of the blood samples were reassessed randomly for quality assurance by the national reference laboratory. The coefficients of variation were 1.7%–3.8% for all laboratory measurements.

A history of diabetes mellitus or recommendation of diabetic drugs or an FBG ≥125 was defined as diabetes.

Statistical analysis

Mean blood pressure, demographic, anthropometric and laboratory values with related standard deviations were calculated by sex separately. The characteristics of the population were compared between men and women using independent *t*-test and Mann Whitney test.

Confirmatory factor analysis was conducted with AMOS software by the use of maximum likelihood estimation method to evaluate various single factor models of MetS in which blood pressure, triglyceride (TG), high density lipoprotein (HDL), FBS and obesity measures served as indicators of MetS. Mean arterial pressure (MAP) as a combination of systolic and diastolic blood pressure was taken into account as an indicator of blood pressure and the ratio of TG to HDL as a single indicator of dyslipidemia was used to evaluate the protective effect of HDL. To obtain a normal distribution for TG/HDL, WHR, WHtR and BMI, the following transformations were able to provide the normal distribution: log TG/HDL, log WHR, SQRT (BMI) and log (WHtR+C). C was determined based on the minimum value of WHtR in population (0.33 in men and 0.3 in women) [C = 1-min{WHtR}]. Using these transformations, a normality assumption was met for all variables except for WHR in men's population. The sample size in total men and non-diabetic men was >2500. We know in a sample size >2500, ML works well, if normal assumption was violated.[20]

We built a single factor model of MetS similar to Plavedall's study,[9] though in our study FBS was used instead of HOMA indices. Thus, we had four hypothesized single factor models of MetS differentiated from each other by four obesity indices of WC, WHR, WHtR and BMI.

Chi-square test with different fit indices, including comparative fit index (CFI), goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), Akaike's information criterion (AIC) and root mean square error of approximation (RMSEA) were used to evaluate the models. The Chi-square test was used to perceive the potential difference between estimated population and sample covariance matrix of which a significant difference can show a lack of fit of the model with the sample data. However, a high sample size increases the power of the study to detect the discrepancy between two matrices and thus raises the chance of rejection of the model.[21]

Therefore, a significant result of Chi-square is not considered a reliable finding to reject the model and thus the other fit indices

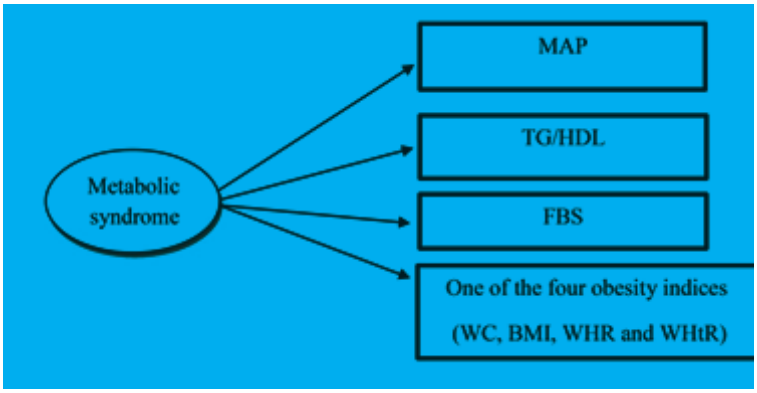

Figure 1. A schematic diagram of different single models of MetS discriminated by the obesity indices. MAP = mean arterial pressure; TG = triglyceride; HDL = high density lipoprotein; FBS = fasting blood sugar; WC = waist circumference; BMI = body mass index; WHR = waist to hip ratio; WHtR = waist to height ratio.

Table 1. Means and related standard deviations of demographic, anthropometric, laboratory characteristics and blood pressure values.

Population characteristics	Total (n = 5616)	Male (n = 3146)	Female (n = 2470)	P-value
Age	43.2 ± 15.2	43.3±15.5	43.1±14.8	0.727
DBP (mm Hg)	76.2 ± 12.8	76.6±12.7	75.7±12.9	0.010
SBP (mm Hg)	116.2 ± 16.4	117.1±15.5	115.1±17.4	<0.001
MAP (mm Hg)	89.5 ± 13.1	90.1±12.8	88.8±13.5	<0.001
FBS (mg/dL)	100.7 ± 35.2	98.3±29.5	103.7±41.1	<0.001
TG (mg/dL)	144.2 ± 98.3	146.9±99.6	140.8±96.5	0.026
HDL (mg/dL)	44.7±11.8	43.3±11.4	46.5±12.1	<0.001
WC (cm)	91.1±12.9	90.7±12.4	91.5±13.4	0.035
BMI (Kg/m^2)	27.9±5.4	26.5±4.6	29.7±5.7	<0.001
WHR	0.8897±0.0883	0.8977±0.0855	0.8569±0.0866	<0.001
WHtR	0.5569±0.0879	0.5340±0.0770	0.5860±0.0922	<0.001

BMI = body mass index; DBP = diastolic blood pressure; FBS = fasting blood sugar; HDL = high density lipoprotein; MAP = mean arterial pressure; SBP = systolic blood pressure; TG = triglyceride; WC = waist circumference; WHR = waist to hip ratio; WHtR = waist to height ratio.

must be used, as well. RMSEA, one of these indices, reveals a lack of fit in a hypothesized model through comparison with a perfect (saturated) model and thus a lower value of it is related to a better fit. Hu and Bentler suggested a threshold of 0.06 for RMSEA, while Browne and Cudeck proposed using a value ≤ 0.05 for the RMSEA as a threshold for a close fit.[22,23] However, a lower limit of the RMSEA's confidence interval ≤ 0.05 emphasizes on an acceptable model while an upper limit ≥0.08 or 0.1 shows an inappropriate model.[23]

On the other hand, using CFI as an incremental fit index, we can compare the hypothesized model with the model in which the covariance among observed variables is assumed zero (null model). Thus, this index can show relative fit improvement of the hypothesis model in comparison with that of the null model.[24] This index varies between zero and one and values closer to one (CFI ≥ 0.95) indicate that the model is appropriate.[25]

The proportion of a covariance in a sample data matrix which can be explained by the model is determinable by GFI.[26,27] Its range is usually between zero and one and a value closer to one (GFI ≥ 0.90 or 0.95) indicates that the model is more appropriate. The above cutoffs for GFI can be applied more in a large sample size.[28]

We also reported the results of AIC because it can be used to compare alternative models based on the same variables. Due to a lack of dependency on sample size, it can be used to evaluate the models in different populations (cross validation). No cutoff point was proposed for this index, but a lower AIC denotes a better fit.[27,29]

Results

Demographic, anthropometric, laboratory and blood pressure characteristics of participants are presented in Table 1. No difference was detected between the mean age of men and women. While the values of waist circumference, BMI and HDL were significantly higher in women, the values of weight, WHR, DBP, SBP, MAP and TG were significantly higher in men. The P-values for all significant comparisons were less than 0.001 except for waist circumference (P-value = 0.035), DBP (P-value = 0.010) and TG (0.026). The prevalence of diabetes was 8.8% (278) in men and 16.5% (407) in women.

Model evaluations

Although the Chi-square test was significant for all models in general population, neither of them could be rejected based on this test due to the large sample size of our study. Thus, we have provided the results of RMSEA, AGFI, GFI, CFI, and AIC. All single factor models had appropriate fit indices with CFI > 0.95, GFI > 0.95 and RMSEA < 0.08 in non-diabetic population, wherein all models obtained the best values of fit indices in men and good fit indices in women. In general population of men, the single factor models built based on waist to hip ratio (WHR) (Chi-square = 6.9, df = 2, P-value = 0.031, RMSEA = 0.028, CI = 0.007–0.052, CFI = 0.994, GFI = 0.999, and AIC = 22.9) and WHtR (Chi-square = 9.97, df = 2, P-value = 0.007, RMSEA = 0.036, CI = 0.016–0.059, CFI = 0.992, GFI = 0.998, and AIC = 25.97) were fitted properly with data while in general population of women, the model based on WHR obtained better fit indices (Chi-square = 7.5, df = 2, P-value = 0.023, RMSEA = 0.033, CI = 0.011–0.060, CFI = 0.994, GFI = 0.998, and AIC = 23.5). The WHtR yielded the better standardized regression weights. More details are reported in Table 2. Finally, a sample correlation for related risk factors is reported in table 3 in which the half above the diameter is related to women.

Discussion

The present study revealed that a single factor model of MetS in which blood pressure, HDL, TG, FBS, and obesity indices were used as indicator variables fits the data well. The models were appropriate in both men and women. The results were exact when we excluded the diabetic patients from our study, particularly in men, where all model fit indices showed very appropriate values. As a result, it is possible the diabetic patients show a different factor structure from non-diabetic people.

According to the findings of the present study, a single underlying cause may be imagined for a constellation of clinical risk factors, including hypertension, dyslipidemia, high FBS and obesity, although the pathophysiology of this causal relationship remains unknown.[10] In other words, a systematic set of interrelations among these risk factors can be attributed to a single underlying cause named the metabolic syndrome. One study in China also confirmed the validity of a single-factor model built based on waist circumference, triglyceride, fasting plasma glucose and mean arterial blood pressure similar to our findings.[11] Further-

Table 2. Model fit indices and regression weights for all models in total population and non-diabetic people by sex.

Models	Model fit indexes						Standardized regression weights
	Chi square	CFI	GFI	AGFI	RMSEA	AIC	
Male ≥ 18 and ≤ 75, N = 3146							
MAP, TG/HDL, FBS, WHR	Chi-square = 6.9 (df = 2, *P*-value = 0.031)	0.994	0.999	0.995	0.028 (CI = 0.007–0.052, *P*-value = 0.931)	22.9	MAP = 0.442, TG/HDL = 0.444, FBS = 0.291, WHR = 0.688
MAP, TG/HDL, FBS, WHtR	Chi-square = 9.97, (df = 2, *P*-value = 0.007)	0.992	0.998	0.992	0.036 (CI = 0.016–0.059, *P*-value = 0.829)	25.97	MAP = 0.467, TG/HDL = 0.450, FBS = 0.247, WHtR = 0.774
MAP, TG/HDL, FBS, WC	Chi-square = 16.5 (df = 2, *P*-value < 0.001)	0.986	0.997	0.987	0.048 (CI = 0.028–0.071, *P*-value = 0.513)	32.5	MAP = 0.482, TG/HDL = 0.450, FBS = 0.218, WC = 0.794
MAP, TG/HDL, FBS, BMI	Chi-square = 26.9 (df = 2, P-value < 0.001)	0.976	0.996	0.979	0.063 (CI = 0.043–0.085, *P*-value = 0.134)	42.9	MAP = 0.476, TG/HDL = 0.468, FBS = 0.187, BMI = 0.780
Male ≥ 18 and ≤ 75 without diabetes mellitus, N = 2868							
MAP, TG/HDL, FBS, WHR	Chi-square = 0.758 (df = 2 *P*-value = 0.685)	1.000	1.000	0.999	0.000 (CI = 0.000–0.028, *P*-value = 0.999)	16.8	MAP = 0.436, TG/HDL = 0.428, FBS = 0.259, WHR = 0.686
MAP, TG/HDL, FBS, WHtR	Chi-square = 1.200 (df = 2, *P*-value = 0.550)	1.000	1.000	0.999	0.000 (CI = 0.000–0.032, *P*-value = 0.998)	17.2	MAP = 0.436, TG/HDL = 0.422, FBS = 0.267, WHtR = 0.824
MAP, TG/HDL, FBS, WC	Chi-square = 0.172 (df = 2, *P*-value = 0.917)	1.000	1.000	1.000	0.000 (CI = 0.000–0.014, *P*-value = 1.000)	16.2	MAP = 0.455, TG/HDL = 0.422, FBS = 0.244, WC = 0.843
MAP, TG/HDL, FBS, BMI	Chi-square = 0.051, (df = 2 *P*-value = 0.975)	1.000	1.000	1.000	0.000 (CI = 0.000–0.000, *P*-value = 1.000)	16.1	MAP = 0.447, TG/HDL = 0.436, FBS = 0.235, BMI = 0.844
Female ≥ 18 and ≤ 75, N = 2470							
MAP, TG/HDL, FBS, WHR	Chi-square = 7.5 (df = 2, *P*-value = 0.023)	0.994	0.998	0.992	0.033 (CI = 0.011–0.060, *P*-value = 0.825)	23.5	MAP = 0.463, TG/HDL = 0.538, FBS = 0.430, WHR = 0.689
MAP, TG/HDL, FBS, WHtR	Chi-square = 32.2 (df = 2, *P*-value < 0.001)	0.971	0.993	0.967	0.078 (CI = 0.056–0.103, *P*-value = 0.020)	48.2	MAP = 0.516, TG/HDL = 0.534, FBS = 0.358, WHtR = 0.711
MAP, TG/HDL, FBS, WC	Chi-square = 35.7 (df = 2, *P*-value < 0.001)	0.934	0.993	0.964	0.083 (CI = 0.060–0.107, *P*-value = 0.009)	51.7	MAP = 0.519, TG/HDL = 0.546, FBS = 0.358, WC = 0.694
MAP, TG/HDL, FBS, BMI	Chi-square = 68.3 (df = 2, *P*-value < 0.001)	0.912	0.987	0.933	0.116 (CI = 0.093–0.140, *P*-value < 0.001)	84.3	MAP = 0.520, TG/HDL = 0.544, FBS = 0.333, BMI = 0.531
Female ≥ 18 and ≤ 75 without diabetes mellitus, N = 2063							
MAP, TG/HDL, FBS, WHR	Chi-square = 3.2 (df = 2, *P*-value = 0.198)	0.998	0.999	0.996	0.017 (CI = 0.000–0.050, *P*-value = 0.948)	19.2	MAP = 0.472, TG/HDL = 0.527, FBS = 0.367, WHR = 0.651
MAP, TG/HDL, FBS, WHtR	Chi-square = 4.39 (df = 2, *P*-value = 0.114)	0.997	0.999	0.995	0.024 (CI = 0.000–0.055, *P*-value = 0.907)	20.39	MAP = 0.485, TG/HDL = 0.511, FBS = 0.368, WHtR = 0.744
MAP, TG/HDL, FBS, WC	Chi-square = 4.76 (df = 2, *P*-value = 0.092)	0.993	0.999	0.994	0.026 (CI = 0.000–0.057, *P*-value = 0.889)	20.8	MAP = 0.488, TG/HDL = 0.519, FBS = 0.361, WC = 0.722
MAP, TG/HDL, FBS, BMI	Chi-square = 7.0 (df = 2, *P*-value = 0.030)	0.992	0.998	0.991	0.035 (CI = 0.009–0.065, *P*-value = 0.768)	23.0	MAP = 0.491, TG/HDL = 0.518, FBS = 0.352, BMI = 0.601

CFI = comparative fit index; GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; RMSEA = root mean square error of approximation; AIC = Akaike's information criterion; MAP = mean arterial pressure; TG = triglyceride; HDL = high density lipoprotein; FBS = fasting blood sugar; WHR = waist to hip ratio; WHtR = waist to height ratio; WC = waist circumference; BMI = body mass index.

Table 3. Sample correlations for related risk factors.

	WC	BMI	WHR	WHtR	MAP	TG/HDL	FBS
General population (diabetic and non- diabetic participants); N = 3146 in men and 2470 in women							
WC	1	-	-	-	0.381	0.367	0.206
BMI	-male	1	-	-	0.311	0.306	0.094
WHR	-	-	1	-	0.334	0.363	0.291
WHtR	-	-	-	1	0.388	0.377	0.224
MAP	0.388	0.378	0.310	0.367	1	0.241	0.175
TG/HDL	0.356	0.366	0.299	0.346	0.199	1	0.259
Glucose	0.160	0.123	0.202	0.184	0.099	0.154	1
Only non-diabetic participants; N = 2868 in men and 2063 in women							
WC	1	-	-	-	0.361	0.370	0.252
BMI	-	1	-	-	0.310	0.303	0.194
WHR	-	-	1	-	0.318	0.340	0.231
WHtR	-	-	-	1	0.369	0.376	0.268
MAP	0.383	0.378	0.298	0.358	1	0.241	0.160
TG/HDL	0.355	0.368	0.292	0.346	0.194	1	0.216
FBS	0.207	0.198	0.183	0.223	0.105	0.105	1

BMI = body mass index; FBS = fasting blood sugar; HDL = high density lipoprotein; MAP = mean arterial pressure; TG = triglyceride; WC = waist circumference; WHR = waist to hip ratio; WHtR = waist to height ratio.

more, in addition to adults, a single factor model was also confirmed in children and young adults.[10,30]

We also compared various models discriminated only based on obesity indices, of which the model built based on WHR showed the best fit indices among the four evaluated models when the general population was included. However, the model based on WHtR yielded better standardized regression weights than other models, although its related fit indices were slightly less appropriate than WHR. On the other hand, when the data were analyzed only for non-diabetic participants, the models built according to WC and BMI showed slightly better fit than other models in non-diabetic men while the model built based on WHR yielded slightly more appropriate fit indices compared to other models in women. However, the regression weights were better when the models were built based on WHtR and WC compared to WHR both in the entire population and diabetic patients. Totally, the model based on WHtR obtained both appropriate factor weights and fit indices, particularly in non-diabetic populations and all men (diabetic and non-diabetic men). Based on some previous studies, WHtR demonstrated a stronger relationship with cardiovascular and metabolic disorders compared to other obesity indices.[31,32]

Finally, the model built based on BMI was not adequately fitted with the data, particularly in the general population (diabetic and non-diabetic) of women and also obtained lower appropriate fit indices than other models in non-diabetic women. It is not far from our expectation that the model built based on BMI could not be fitted adequately with data, since among the four obesity measures, only BMI is not considered as a central obesity index. On the other hand, while WC is taken into account as a popular central obesity index, WHR and WHtR are adjusted forms of central obesity indices in terms of HC and height, respectively. Moreover, WC is associated with the hypertrophic form of obesity, a high value of which can yield somewhat predictive capability for the occurrence of metabolic alterations such as insulin resistance. However, WHR as an adjusted form of WC with comparable ability can help better to discriminate between android and gynoid fat distribution.[33] This may explain why the model built based on WHR was adequately able to fit empirical data.

Solera-Martínez compared two models of MetS based on WC and WHtR and proposed that the former yields better fit indices. This result is not in line with our findings, although only two models were evaluated in that study and a model that used WHR was not hypothesized.[10] Furthermore, in contrast with the present study, Gómez-Marcos *et al.* proposed that the models based on BMI in men and WC in women show better fit results.[12] In a comparison with the Gomez study, in the present study, the models built based on BMI and particularly WC were almost exactly fitted with the sample data in non-diabetic men and were appropriately fitted in non-diabetic women. On the other hand, in the general population (diabetic and non-diabetic people) models built based on WC and BMI were fitted acceptably with sample data in men although they were not the best.

The inconsistent findings among various studies can be attributed to differences in age composition, variables used for model building, sample size and also ethnicity and race differences among studies. However, a single factor model of MetS was confirmed in most studies despite that there is not any general agreement on which one of the obesity measures is able to explain it better.

The present study had a community-based design carried out among adults in a wide age range and almost an optimal sample size in order to implement the CFA. However, this study had some limitations. We did not use the HOMA index as an insulin resistance index which signifies that we could not properly compare our findings in this regard with other studies. Although the normality assumption was not met in some models due to non-normality distribution of data of WHR in men, in a sample size of ≥ 2500 the ML can provide reliable results.[20]

In conclusion, throughout this study, the efficiency of single factor model of MetS was supported by the results of confirmatory factor analysis. The best models were different according to sex and population of study.

The authors declare that there is no conflict of interest and no relationship with industries.

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