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Original Article

Chronic medical conditions based obesity phenotypes: A two-step cluster analysis of a representative sample of obese American adults

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ABSTRACT

Background and objective: Although obesity is a heterogeneous disease, little is known regarding chronic medical conditions (CMCs) that defines variability in obese populations. The characterization of obese populations using CMCs rather than categorization using BMI alone can advance understanding of obesity. The aims of this study are to phenotype obesity in a large representative sample of non-Hispanic White (NHW), non-Hispanic Black (NHB) and Mexican American (MA) obese adults using CMCs, and assess relationship between resulting phenotypes and self-rated health (SRH).

Methods: Sex-specific two-step cluster analysis was used to phenotype obese participants (n = 12,547) to CMC-based clusters. The prevalence of CMCs and lifestyle risk factors in each cluster was assessed. Sex and race/ethnic specific association between cluster membership and SRH was determined using odds ratio (OR) from logistic regression analysis.

Results: Distinct subgroups of obese men and women were observed: moderate dyslipidemic healthy young obese men, hypertensive-dyslipidemic middle-age obese men, hypertensive young obese men, hypertensive-dyslipidemic-asthmatic middle-age obese men, and syndemic elderly obese men, healthy young obese women, hypertensive-dyslipidemic middle-age obese women, dyslipidemic young adult obese women, syndemic middle-age obese women, and syndemic elderly obese women. Participants in the more CMCs symptomatic clusters reported high rates of behavioral risk factors and showed significantly greater odds of poor SRH than participants in the less symptomatic clusters. Compared to obese persons who are asymptomatic for CMCs, syndemic elderly obese and women men had much higher increased ORs for poor SRH with values of 3.88 [95% CI = 2.41–6.26], 3.96 [95% CI = 1.86–8.30] and 7.25 [95% CI = 2.41–9.6] for NHW, NHB and MA men, respectively. The corresponding ORs for women are 4.08 [95% CI = 2.71–6.14], 4.01 [95% CI = 2.40–6.69], and 2.62 [95% CI = 1.32–5.19], respectively.

Conclusion: Obesity treatment and intervention should consider heterogeneity within obese persons and pay greater attention to obesity related co-morbidities and metabolic manifestations.

1. Introduction

The increasing prevalence of obesity is recognized worldwide [1,2], and it is estimated that by 2030 42–51% of American adult population will be obese [3,4]. A body mass index (BMI) of 30 kg/m^2 or greater classifies persons as obese. Obesity is associated with increased risk for CMCs [5–10] and linked with racial/ethnic differences for many CMCs [11,12]. In the US, African-Americans have significantly higher rates of obesity and many CMCs than White-Americans and other American racial/ethnic minorities [13,14].

The categorization of obesity on the basis of BMI of 30 kg/m^2 or greater assumes homogeneity within obese persons and fail to recognize variation within obese persons. Indeed, evidence of heterogeneity of obesity is supported by reports describing the existence of a subgroup of obese persons described as "healthy obese phenotype" or "metabolically healthy obesity" that are protected against obesity-related metabolic complications [15,16].

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Multiple studies indicate that 10–25% of obese individuals are metabolically healthy [17,18]. Using the NHANES, Wildman et al. [19] found a prevalence of metabolically healthy obesity of 32% among obese American adults. Some studies report healthy obesity phenotype to be an enduring state in certain obese persons, and about 50–70% of these obese individuals remain metabolically healthy without or with only few CMCs [20,21]. In a large population-based study examining the natural course of metabolically healthy obese individuals across 30 years, participants who maintained metabolically healthy obesity during follow-up were found to have a lower risk of converting to metabolically unhealthy phenotype status (HR = 1·90; 95% CI = 1·66–2·17) [22]. Therefore, understanding the levels of heterogeneity in obesity and associated factors may help to improve public health interventions and treatments of obese populations.

We hypothesize that clustering of CMCs is the root for heterogeneity of obesity as well as metabolically healthy or metabolically unhealthy states. Therefore, a critical issue that is yet to be fully evaluated is the relationship between clustering of CMCs and overall health of obese persons. In this study, we used the 2-step cluster analysis to phenotype obesity in a large representative sample of obese non-Hispanic White (NHW), non-Hispanic Black (NHB) and Mexican Americans (MA) based on CMCs and assess: (1) CMC distribution patterns, and (2) the relationship between patterns of CMCs and common risk factors. We also assessed sex- and-race/ethnic specific association between obesity cluster membership and self-rated overall health. Understanding sex and racial/ethnic level of heterogeneity among obese persons may permit more robust clinical and public health interventions that are tailored based on sex and race/ethnicity of obese persons.

2. Materials and methods

2.1. Data source

Combined cross-sectional data of 13,469 obese persons from the 2001 to 2015 US National Health and Nutrition Examination Surveys (NHANES) are used for this study [23]. NHANES is a multistage, stratified, clustered probability sample of civilian non-institutionalized Americans conducted by the National Center for Health Statistics (NCHS) [23]. The surveys are designed to obtain demographic, socioeconomic, dietary, and health-related information and consist of a standardized in-home interview performed by trained interviewers, and physical examinations performed at a mobile examination center (MEC) [23]. The NCHS institutional review board approves the protocols for NHANES, and informed consent are obtained from all participants [23].

2.2. Study eligibility criteria

This study is limited to NHW, NHB and MA adults (age $\geq$ 20) with BMI of 30 kg/m^2. Pregnant women are excluded from this study.

2.3. Study variables

Variables for this study include age, weight, height, education, health insurance, physical activity, alcohol use, smoking, blood pressure, blood glucose, lipids, self-reported overall health, and selected CMCs. In NHANES, race/ethnicity, education, leisure time physical activity and insurance status, and age of participants were self-reported by participants and anthropometric measurements were obtained in MECs by trained personnel. Height and weight were measured by validated methods [23]. In this study, education is coded into 2 categories: (1) less than high school, (2) high school education and greater. We used the survey questions regarding types of physical activity during the past 30 days and coded as physically active and physically inactive in this study. In this study, alcohol use is defined based on the survey question: *In the past* 12 months*, how often did you drink any type of alcoholic beverage?* Among those who drank any alcoholic beverage in the past 12 months, men who drank $\geq$5 drinks and women who drank $\geq$4 drinks, on average, on drinking days are classified as alcohol users [24]. In this study, smoking is categorized into current smokers and non-smokers. In NHANES, participants were asked: *Are you covered by health insurance or some other kind of health care plan?* Participants who answered negatively are classified as medically uninsured in this study. In NHANES, blood pressure was measured using standardized procedures, and blood glucose was obtained after overnight fasting. To determine self-rated health condition, participants were asked in NHANES: *In general, would you say your health is "excellent, very good, good, fair, or poor?*" In this study, participants who reported "excellent, very good, or good" are categorized as having "good overall health", while those who reported their health as "fair, or poor" as having "poor overall health" [25]. The primary variable for this study is obesity, defined using BMI of 30 kg/m^2 or greater.

2.4. Chronic medical conditions

We defined CMCs to include medical diagnoses as well as health states and conditions that confer increased risks for poor health. Ten CMCs are assessed for this study: hypertension, arthritis, stroke, cancer, congestive heart failure, coronary heart disease, chronic obstructive pulmonary disease (COPD), diabetes, asthma, and dyslipidemia. These medical conditions are listed as priority conditions by the Agency for Healthcare Research and Quality [26] and the Robert Wood Johnson Foundation as disorders that are amenable to public health and clinical interventions [27]. We were only able to assess those CMCs described in the NHANES. In this study, CMCs are based on participants self-report in NHANES. However, we defined hypertension, diabetes and dyslipidemia status using additional survey questions, measurements and laboratory values. **Hypertension** is defined as diastolic blood pressure (DBP) $\geq$ 90 mm Hg, systolic blood pressure (SBP) $\geq$ 140 mm Hg or current treatment with prescribed anti-hypertension medication [28]. On the NHANES questionnaire, participants were asked if a doctor or other health professional ever told them they had any of these diseases: **arthritis, asthma, cancer, stroke, cancer, congestive heart failure, and coronary heart disease**. In this study, participants who answered yes are regarded as disease positive and those who answered no are classified as disease negative. **COPD** status (chronic bronchitis and emphysema) was ascertained using self-report or a participant response that the diagnosis had been made previously by a doctor or health professional. In NHANES, participants were asked: (1) *Do you usually cough on most days for 3 consecutive months or more during the year?* (2) *Do you usually bring up phlegm on most days for 3 consecutive months or more during the year?* In this study, participants are classified as having COPD if they had previous history of a COPD diagnosis or responded affirmatively to the above questions. In NHANES, participants were asked:" have *you ever been told by a doctor or health care professional that you have diabetes or sugar*?" and "*are you taking diabetic pills to lower your blood sugar*?" In this study, **diabetes** is defined as answering yes to either of these questions or having a fasting blood glucose (FBG) of 125 mg/dl and greater or an oral glucose tolerance test (OGTT) value of 200 mg/dl and greater [29]. **Dyslipidemia** status is based on participants' self-report constructed from these NHANES questions: (1) *Have you ever been told by a doctor or other health professional that your blood cholesterol level was high?* (2) *To*

lower your blood cholesterol, have you ever been told by a doctor or other health professional to take prescribed medicine? Dyslipidemia is defined by an affirmative answer to either of the above questions or having a serum low-density cholesterol (LDL-C) value of 100 mg/dl or greater or high-density cholesterol (HDL-C) of less than 40 mg/dl or serum triglycerides of 150 mg/dl or greater [30].

2.5. Cluster analysis

Obese participants with at least one CMCs and no missing report regarding the ten chronic conditions listed above are included in the cluster analysis. Two-step cluster analysis using a log-likelihood distance measure was performed using IBM SPSS Statistics version 25 (IBM, Armonk, NY, USA). The two-step cluster analysis classifies obese participants who are similar to each other with respect to the ten CMCs, but different from other participants. A two-step cluster analysis identifies group segmentations by running pre-clustering first, and then by hierarchical methods [31]. This technique can detect latent relationships within and between participants with multiple distinct characteristics. Optimal cluster solution was determined using the Akaike information criterion [32]. The quality of fit of the resulting clusters was evaluated using the silhouette measure of cohesion and separation [33]. The silhouette measure contrasts the average distance among elements in the same cluster (within cluster cohesion) with the average distance to elements in other clusters (between-cluster separation).

2.6. Statistical analysis

In order to account for the unequal probability of selection, oversampling, and nonresponse, we applied appropriate sample weights, strata and cluster variables to all analyses. We compared demographic and behavioral variables characteristics stratified by cluster, sex and race/ethnicity. Cluster differences for categorical and continuous variables were assessed using the chi-squared and one-way analysis of variance tests, respectively. We tested sex and race/ethnic-specific association between cluster membership (independent variable) and self-rated overall health (dependent variable) using odds ratio from logistic regression analysis. In the logistic regression models, we compared odds of poor self-rated health for clusters membership using asymptomatic individuals as reference group and controlled for behavioral variables characteristics, including age, marital status, income, education, and behavioral variables including physical activity, alcohol use and smoking.

3. Results

3.1. Basic characteristics of study population

A total of 13,469 obese persons (5984 men and 7485 women) were eligible for this study and 922 (6.84%) participants are classified as asymptomatic i.e. not possessing any CMCs (Table 1). The asymptomatic individuals are younger, of lower weight and waist circumference, and have significantly lower BMI and better self-rated overall health compared to symptomatic participants ($P < .01$).

3.2. Heterogeneity of obesity phenotypes

The cluster analyses of symptomatic participants revealed the existence of five distinct subgroups of obese men and women. Features of the subgroups of obese men are as follows: Cluster 1 is characterized by healthy young obese men with low rate of dyslipidemia, “moderate dyslipidemic healthy young obese men”; Cluster 2 is characterized by middle-age obese men with high rates of hypertension and dyslipidemia, “hypertensive-dyslipidemic middle-age obese men”; Cluster 3 is characterized by hypertensive young obese men, “hypertensive young obese men”; Cluster 4 is characterized by middle-age obese men with high rates of hypertension, dyslipidemia and asthma, “hypertensive-dyslipidemic-asthmatic middle-age obese men”; and Cluster 5 consists of elderly obese men with high rates of all studied CMCs, “syndemic elderly obese men”. In men, the ten CMCs used in the two-step cluster analysis produced a silhouette coefficient of 0.70 that suggests good data partitioning. CHF, dyslipidemia, hypertension, asthma, cancer, and coronary heart disease are the most important CMCs that emerged from the five clusters, whereas, arthritis, diabetes, COPD and stroke are not as prominent in men. (Fig. 1A).

Cluster specific features of obese women are as follows: Cluster 1 consists of healthy young obese women with the lowest rate of CMCs, “healthy young obese women; Cluster 2 is characterized by hypertensive middle-age obese women with high rate of dyslipidemia, “hypertensive-dyslipidemic middle-age obese women”; Cluster 3 consists of young obese women with dyslipidemia, “dyslipidemic young adult obese women”; Cluster 4 is characterized by middle-aged obese women with high rates of CMCs, “syndemic middle-age obese women”; and Cluster 5 is characterized by elderly obese women with high rates of all CMCs, “syndemic obese elderly women”. In women, the ten CMCs used in two-step cluster analysis produced a silhouette coefficient of 0.75 that is suggestive of good data partitioning. In women, COPD, dyslipidemia, hypertension, diabetes, cancer, asthma and arthritis are the most important CMCs that emerged from the five clusters, while CHD, CHF and stroke are least prominent (Fig. 1B).

Men and women in the more symptomatic clusters (Clusters 3–5) have significantly more CMCs and higher rates of poor self-rated health compared with asymptomatic men and women assigned to Clusters 1 and 2. As shown in Table 1, behavioral risk factors tend to be associated with cluster assignments and more asymptomatic individuals report their marital status as single compared to symptomatic participants ($P < .01$). The racial/ethnic composition of the clusters differed markedly and participants assigned Cluster 1 have lower proportions of NHB than other clusters. Men and women in the five clusters are distinctly different in terms of age, income, medical insurance, smoking, physical activity, alcohol use, marital status, education, race/ethnicity, as well as type of CMCs. As shown, men and women participants assigned to Cluster 1 are younger, heavier, have higher waist girt and have fewer number of CMCs compared to participants in other clusters.

3.3. Sex and racial/ethnic patterns of CMC clustering and behavioral risk factors

The patterns of CMC clustering in NHW, NHB and MA men and women are depicted using radar plots to display simultaneous distribution of CMCs (Fig. 2 and 3) in the form of a two-dimensional axes starting from the same point. The relationships of CMC clustering with behavioral risk factors including low income, lack of insurance, lack of physical activity, smoking, alcohol intake, low educational status, and poor self-rated overall health are shown in Tables 2 and 3.

3.4. Patterns of CMC clustering and behavioral risk factors in NHW, NHB and MA obese men

Cluster 1: Dyslipidemia is the predominating CMC in Cluster 1 with rates of 68%, 61% and 78% in NHW, NHB and MA, respectively. With the exception of MA men, higher income earners and fewer alcohol users characterize this cluster while more participants in

Table 1
Basic demographic and behavioral characteristics of Obese US Americans stratified by Chronic Medical Condition Clusters.

CHRONIC MEDICAL CONDITIONS CLUSTER							
Variables	Asymptomatic	1	2	3	4	5	
MEN							
N (%)	272 (4.5)	993 (16.6)	921 (15.4)	2304 (38.5)	695 (11.6)	1071 (17.9)	P-value
Age (yr)	36.4 ± 11.5	40.7 ± 13.2	47.4 ± 16.4	50.0 ± 15.0	45.2 ± 16.7	65.2± 11.7	<.001
Weight (kg)	102.2±14.8	102.7 ±14.8	108.0 ±22.0	107.9 ± 19.3	111.4 ± 20.4	106.9 ± 18.2	<.001
Waist (cm)	110.2±10.8	111.6 ±02.3	115.8 ±12.6	117.0 ± 12.3	118.5 ± 13.7	120.3 ± 11.6	<.001
Body mass index	33.5 ±3.8	35.7± 3.6	35.2 ± 6.2	35.1 ± 5.2	36.0 ± 5.8	35.1 ± 5.0	<.001
No CMCs	–	0.9 ± 0.7	1.4 ± 0.7	2.5 ± 0.7	3.2 ± 1.1	4.5 ± 1.4	<.001
Low Income (%)*	14.6	15.3	18.3	17.2	24.1	25.2	<.001
No Insurance (%)	33.5	32.5	22.3	26.6	22.5	6.3	<.001
Physical inactivity (%)	42.3	43.2	44.5	46.2	47.6	56.9	<.001
Smoking (%)	14.3	16.4	14.2	15.5	18.7	13.1	.017
Alcohol use (%)	10.7	12.6	16.6	16.5	18.6	16.4	.012
Single MS (%)	27.9	20.7	19.9	12.9	22.0	6.7	<.001
LTHS Education (%)	21.7	20.4	24.3	25.1	26.2	29.4	<.001
Ethnicity (%)							<.001
NH White	45.7	47.1	43.8	49.5	34.9	67.5	
NH Black	30.3	22.7	26.7	25.6	36.7	23.8	
Mexican American	24.0	30.3	20.3	24.9	12.5	8.8	
Poor self-rated health	18.0	24.8	27.0	27.9	30.7	42.1	<.001
WOMEN							
N (%)	650 (8.0)	1348 (18.0)	1092 (14.6)	1755 (23.4)	1849 (24.7)	1441 (19.3)	
Age (yr)	33.9 ±9.6	40.2 ±13.4	40.6 ± 13.5	55.0 ± 14.7	50.2 ±12.9	61.8 ± 15.7	<.001
Weight (kg)	91.9±15.1	92.9 ±17.5	92.4 ± 15.9	93.8 ± 18.2	93.9 ±18.7	98.3 ± 20.1	<.001
Waist (cm)	106.3 ±10.8	108.4 ±12.2	109.6 ± 11.6	111.4 ± 12.0	114.0 ±11.6	114.2 ±13.4	<.001
Body mass index	35.0±4.6	35.2± 5.6	35.6 ± 5.3	36.3 ± 5.9	36.8 ± 6.9	37.8± 6.9	<.001
No CMCs	–	0.5 ± 0.4	1.4 ± 0.6	2.5 ± 0.7	2.5± 0.7	3.6 ± 1.5	<.001
Low Income (%)*	19.4	20.7	27.9	30.7	34.1	18.0	<.001
No Insurance (%)	29.1	29.6	17.4	25.3	13.3	17.5	<.001
Physical inactivity (%)	56.0	56.8	59.8	61.1	59.0	68.6	<.001
Smoking (%)	11.8	12.5	16.8	12.3	10.4	22.4	<.001
Alcohol use (%)	17.2	15.1	16.5	16.8	12.7	15.8	.008
Single MS (%)	28.7	23.5	23.8	13.3	10.1	18.0	<.001
LTHS Education (%)	12.5	16.0	16.8	17.3	20.4	22.4	<.001
Ethnicity (%)							<.001
NH White	36.0	34.9	43.8	45.4	47.5	50.4	
NH Black	32.6	36.7	26.7	35.4	32.4	36.6	
Mexican American	31.4	28.4	19.3	29.5	20.1	13.0	
Poor self-rated health	14.8	18.0	27.0	27.9	30.7	35.2	<.001

NH, non-Hispanic; LTHS, less than high school; SRH, MS, Marital status; PA, Physical activity; CMCs, Chronic medical conditions* Less than $25,000 annual income.

the cluster have greater than high school education compared to participants in other clusters.

Cluster 2: Hypertension and dyslipidemia are the distinguishing symptoms of Cluster 2, with prevalence of 100% in NHW, NHB and MA. The average number of CMCs in this cluster is 2.5. NHB men in this cluster have significantly higher BMI (38.5 kg/m^2) compared to NHW (35.2 kg/m^2) and MA (34.7 kg/m^2).

Cluster 3: Hypertension is the discriminating symptoms of participants assigned to Cluster 3 with rates of 98.6%, 100%, and 99.4% in NHW, NHB and MA obese men, respectively. Rates of smoking, and alcohol use are higher among participants assigned to cluster 3 compared with asymptomatic men and those assigned to other clusters.

Cluster 4: Cluster 4 is characterized by preponderance of mixed profiles of CMCs ranging from zero to 84.4%. Asthma, hypertension and dyslipidemia are the three most prevalent CMCs in NHW and MA men, with rates of 84.4%, 79% and 78.4% in NHW and 87.8%, 75.4% and 78.4% in MA, respectively. NHW participants of Cluster 4 have much greater prevalence of low income, lack of health insurance, current smoking, and alcohol use compared to participants assigned to clusters 1–3 and 5. Cluster 4 has higher proportions of unmarried NHW, NHB and MA than the participants assigned to other clusters.

Cluster 5: The highest numbers of CMCs in men are recorded in participants assigned to Cluster 5. The top five most prevalent CMCs are hypertension, dyslipidemia, arthritis, diabetes and cancer with rates of 97.3%, 78.1%, 67.6%, 55.6% and 46.8%, respectively in NHW, 97.6%, 73.3%, 60.1%, 73.6% and 20.2%, in NHB and 96.4%, 76.3%, 49.2%, 79.9% and 21.6% in MA, respectively. The rates of physical inactivity and poor education are higher in men of Cluster 5 compared to asymptomatic and persons assigned to other clusters ($P < .001$).

3.5. Patterns of CMC clustering and behavioral risk factors in NHW, NHB and MA obese women

Cluster 1: Hypertension is the only CMC that is prevalent in participants assigned to Cluster 1 with rates of 50.8%, 57.5% and 47.2% in NHW, NHB and MA, respectively. Women assigned to cluster 1 have much higher annual income compared to women in other clusters ($P < 01$). There are significantly higher rate of medically uninsured, lower rates of physical inactivity and lower rate of poor education in NHB in Cluster 1 compared to those in other clusters. Similarly, MA women in Cluster 1 have much higher rates of medically uninsured and alcohol users, and lower rates of physical inactivity, smoking, and lower levels of education compared to MA in other clusters.

Cluster 2: Hypertension, dyslipidemia and arthritis are the distinguishing CMCs in women assigned to this cluster. The prevalence of hypertension is 100% each in NHW, NHB and MA. The

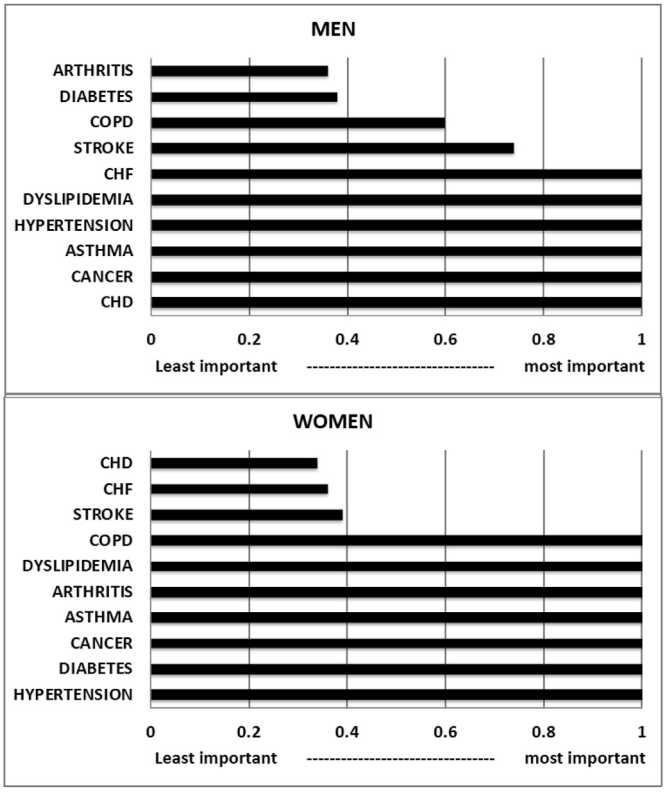

Fig. 1. Variable Importance from two-step Cluster Analysis

rates of dyslipidemia are 84.9%, 81.9% and 85.5% and rates of arthritis are 52.8%, 48.6% and 42.6% in NHW, NHB and MA, respectively. Specific behavioral characteristics of participants assigned to this cluster include higher rates of current smokers and fewer numbers of singles among NHW compared to NHB and MA women.

Cluster 3: The top three CMCs in women of this cluster are dyslipidemia, arthritis and diabetes with rates of 90%, 26.9% and 8.5% for NHW and 86.1%, 19.6% and 12.2% for NHB. The corresponding rates in NHB women are 87.1%, 19.6% and 17.7%, respectively. The behavioral characteristics of women of this cluster include lower rates of physical inactivity in NHW, higher rates of alcohol users, and unmarried participants among NHB, and higher rates of medically unmarried in MA participants.

Cluster 4: This cluster is characterized by the high rates of comorbidities. Hypertension, dyslipidemia, arthritis, diabetes and cancer are the five most prevalent CMCs in NHW and MA women, with rates of 97.3%, 78.1% and 67.6%, 55.7% and 46.8% in NHW and 97.6%, 73.6%, 60.1%, 73.3% and 20.2% in NHB, respectively. Women in this cluster report the highest rates of less than high school education, lower rates of alcohol use and health insurance and being single compared to women assigned to other clusters.

Cluster 5: This cluster is characterized by preponderance of many CMCs that ranged 3.1% for CHF to 84.3% for Asthma in MA. The rates of asthma in this cluster are 80.2%, 83.7% and 84.3% in NHW, NHB and MA, respectively. The rates of poverty and smoking are higher in women in this cluster compared to women assigned to other clusters.

3.6. Association between obesity cluster and self-rated health

The results of race/ethnic specific association between obesity cluster membership and self-rated overall health are shown in Table 4. In both men and women, cluster membership is associated with self-rated overall health. Compared to NHW asymptomatic male participants, being a NHW male participant in Cluster 1, 2, 3, 4 or 5 is associated with 1.21, 1.62, 2.17, 2.51 and 3.88 increased odds of poor self-rated overall health, controlling for age, income, insurance, physical inactivity, smoking, alcohol intake, marital status and education. The corresponding values are 1.05, 1.24, 1.83, 1.78, and 3.96 for NHB, and 1.84, 2.41, 2.78, 2.47 and 7.25 for MA, respectively. Being a NHW female participant in Cluster 1, 2, 3, 4 or 5 is also associated with 1.03, 1.24, 1.75, 2.61 and 4.08 increased odds of poor self-rated overall health compared with NHW asymptomatic female participants, controlling for age, income,

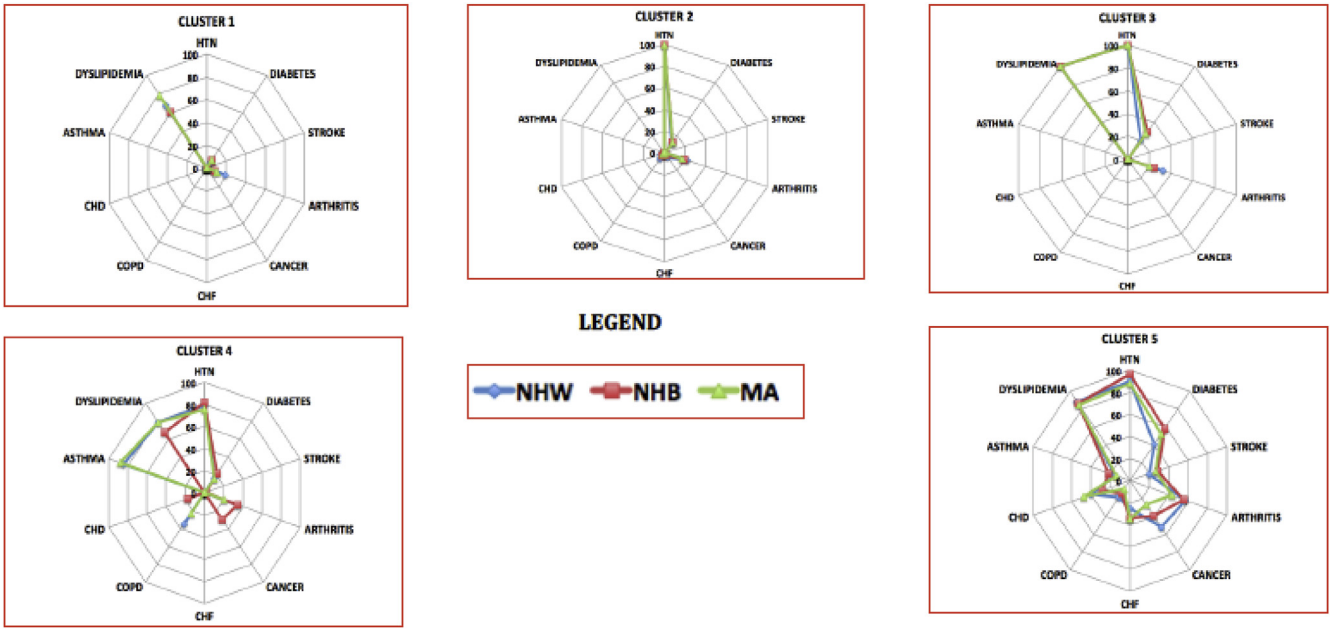

Fig. 2. Radar Plots of Clustering of CMCs in non-Hispanic White (NHW), non-Hispanic Black (NHB) and Mexican American (MA) Obese American Men

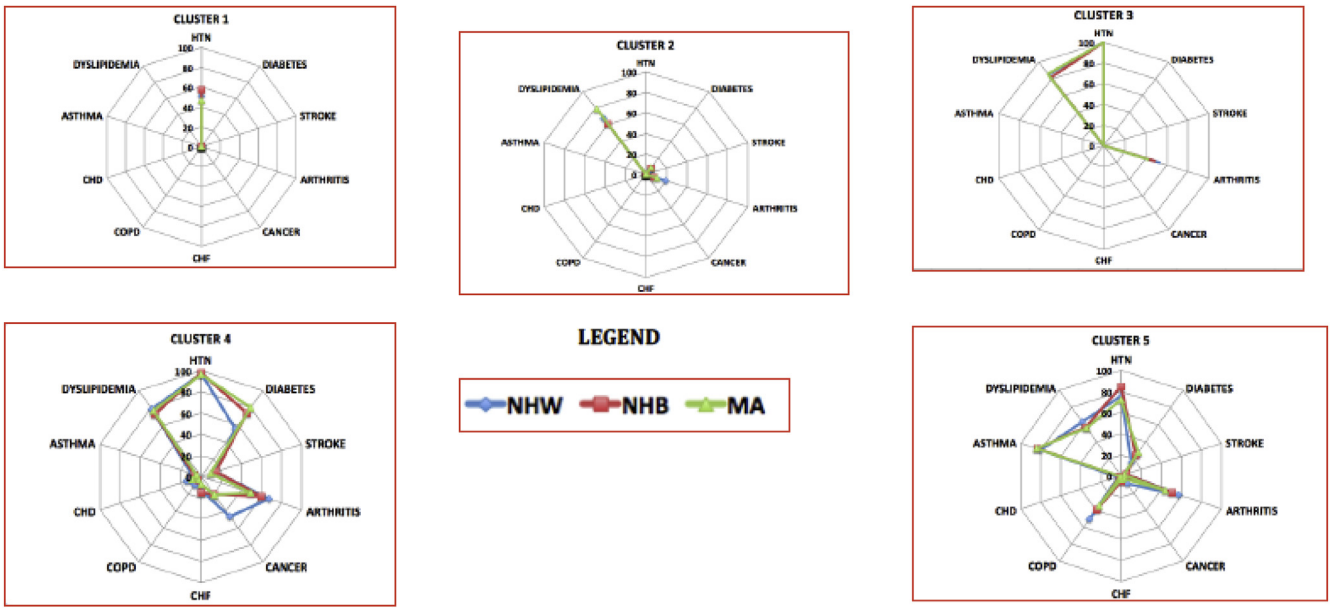

Fig. 3. Radar Plots of Clustering of CMCs in non-Hispanic White (NHW), non-Hispanic Black (NHB) and Mexican American (MA) Obese American Women

Table 2
Demographic and behavioral characteristics of Obese US American men stratified by Chronic Medical Condition Clusters.

CLUSTERS OF CHRONIC MEDICAL CONDITIONS							
Variables	Asymptomatic	1	2	3	4	5	
NON-HISPANIC WHITE MEN							
Age (yr)	39.8 ±12.4	43.1 ±13.4	50.6 ±17.1	51.2 ± 15.6	46.5 ± 16.7	67.0± 11.3	<.001
Weight (kg)	106.1 ±15.1	105.7 ±14.6	108.5 ±20.5	110.7 ± 18.6	112.9 ± 20.6	106.8 ± 16.7	<.001
Waist (cm)	113.0 ±11.4	113.8 ±10.2	117.3 ±11.6z	119.0 ± 11.9	120.4 ± 13.4	121.3 ± 10.8	<.001
Body mass index	33.7 ±4.3	33.6 ± 3.6	34.9 ± 6.9	35.2 ± 5.2	36.2 ± 6.3	34.9 ± 4.6	<.001
No CMCs	–	0.9 ± 0.7	1.5 ± 0.7	2.5 ± 0.6	3.3 ± 1.1	4.5 ± 1.4	<.001
Low Income (%)*	8.9	12.5	18.1	15.5	25.6	22.9	<.001
No Insurance (%)	16.0	17.0	13.6	14.5	18.8	4.2	<.001
Physical inactivity (%)	42.9	42.4	43.3	43.0	42.4	52.7	<.001
Smoking (%)	14.0	20.0	17.5	16.7	21.9	11.5	.017
Alcohol use (%)	8.4	13.2	17.5	19.7	21.6	19.3	.026
Single MS (%)	18.7	17.7	17.2	12.8	17.8	5.3	<.001
LTHS Education (%)	4.7	10.0	15.0	15.0	15.2	23.6	<.001
Poor self-rated health 24.1	28.3	33.4	38.5	45.4	48.5	<.001	
NON-HISPANIC BLACK MEN							
Age (yr)	33.1 ±10.0	38.0 ±12.3	47.0 ±15.4	50.3 ± 14.4	44.3 ± 16.9	63.0± 10.7	<.001
Weight (kg)	106.3±13.7	107.3 ±14.5	112.5 ±22.0	112.4 ± 20.1	113.2 ± 20.7	111.1 ± 21.2	<.001
Waist (cm)	108.5±10.6	110.4 ±11.0	115.7 ±13.3	117.3 ± 13.3	117.3 ± 14.6	119.3 ± 13.4	023
Body mass index	33.8 ±3.5	34.4 ± 4.1	35.8 ± 6.1	38.5 ± 5.7	36.2 ± 5.4	36.0 ± 5.4	<.001
No CMCs	–	0.8 ± 0.7	1.4 ± 0.6	2.5 ± 0.7	3.2 ± 1.2	4.6 ± 1.3	<.001
Low Income (%)*	15.0	16.2	19.2	16.5	19.3	27.1	.060
No Insurance (%)	36.6	31.6	23.3	19.4	23.9	5.6	<.001
Physical inactivity (%)	31.0	34.7	47.9	49.4	48.3	64.3	<.001
Smoking (%)	15.5	18.1	15.3	18.0	16.9	15.9	.848
Alcohol use (%)	5.6	11.4	14.9	15.9	18.6	12.9	.292
Single MS (%)	41.5	36.8	24.3	17.3	24.9	11.2	<.001
LTHS Education (%)	16.9	17.1	22.6	22.8	20.3	35.8	<.001
Poor self-rated health	12.8	28.5	30.0	36.5	42.9	44.4	<.001
MEXICAN AMERICAN MEN							
Age (yr)	3.4 ±11.1	39.9 ±12.8	44.5 ±15.6	49.0 ± 14.6	47.4 ± 18.9	60.6± 12.7	<.001
Weight (kg)	95.0±14.4	96.8 ±14.8	103.3 ±20.3	100.8 ± 17.6	104.1 ± 17.2	101.0 ± 19.1	<.001
Waist (cm)	108.7±10.4	109.9 ±12.3	114.9 ±12.7	114.6 ± 11.5	115.1 ± 10.8	117.2 ± 11.5	.001
Body mass index	33.1 ±3.9	33.4± 3.6	35.2 ± 5.7	34.7 ± 4.6	35.1± 4.7	34.9 ± 5.1	<.001
No CMCs	–	0.9 ± 0.6	1.3± 0.6	2.5 ± 0.8	3.0 ± 1.0	4.3 ± 1.5	<.001
Low Income (%)*	22.4	18.1	18.7	22.2	27.3	30.4	.190
No Insurance (%)	42.6	52.0	35.4	35.7	28.4	19.8	<.001
Physical inactivity (%)	46.4	45.3	47.9	51.4	46.6	61.9	.081
Smoking (%)	12.5	11.2	7.3	10.7	8.1	11.6	.653
Alcohol use (%)	17.9	11.3	17.7	13.1	14.9	11.6	.495
Single MS (%)	17.9	13.6	16.5	7.8	27.0	5.8	<.001
LTHS Education (%)	50.0	47.3	51.2	51.9	56.3	57.0	.908
Poor self-rated health	8.7	17.4	19.1	19.6	23.4	31.4	.051

Table 3
Demographic and behavioral characteristics of Obese US American women stratified by Chronic Medical Condition clusters.

CLUSTERS OF CHRONIC MEDICAL CONDITIONS							
Variables	Asymptomatic	1	2	3	4	5	
NON-HISPANIC WHITE WOMEN							
Age (yr)	34.7 ± 10.1	42.3 ± 14.8	42.5 ±14.6	57.0 ± 15.1	64.2 ± 13.2	50.9± 16.1	<.001
Weight (kg)	95.6 ±14.6	95.8 ± 16.7	94.5 ±14.5	94.9 ± 18.1	94.6 ± 17.8	97.2± 18.2	.037
Waist (cm)	108.5 ±10.7	110.0 ±11.7	109.9 ±11.1	112.5 ± 12.2	114.9 ± 12.4	114.1 ± 13.1	<.001
Body mass index	33.7 ±4.7	36.0± 3.5	35.4 ± 4.7	36.3 ± 6.0	36.7± 6.1	37.0 ± 6.2	<.001
No CMCs	–	0.5 ± 0.3	1.4± 0.6	2.3 ± 0.5	3.6 ± 1.0	3.3 ± 1.5	<.001
Low Income (%)*	16.8	17.4	20.7	22.5	30.0	32.0	<.001
No Insurance (%)	22.6	18.4	16.9	11.6	7.2	13.8	<.001
Physical inactivity (%	51.3	51.0	49.6	57.1	64.3	53.6	<.001
Smoking (%)	14.3	17.3	26.9	13.6	10.9	29.2	<.001
Alcohol use (%)	21.4	17.3	19.9	22.1	15.8	16.9	.020
Single MS (%)	24.5	17.1	16.9	8.0	5.8	13.8	<.001
LTHS Education (%)	8.2	10.6	14.4	16.2	21.1	21.4	<.001
Poor self-rated health	20.4	20.8	22.8	36.4	37.3	42.4	<.001
NON-HISPANIC BLACK WOMEN							
Age (yr)	32.1 ± 8.6	38.6 ± 12.4	39.0 ± 12.6	53.5 ± 14.7	60.4 ± 12.5	48.8 ± 15.5	<.001
Weight (kg)	95.5 ±16.1	97.9 ± 18.6	96.2 ± 16.4	98.3 ± 19.3	99.4 ± 20.9	103.7 ± 21.9	<.001
Waist (cm)	106.6±11.9	109.4 ± 13.8	109.3 ± 12.5	112.3 ± 12.7	115.0 ± 12.9	115.6 ± 14.3	.001
Body mass index	35.9 ±5.3	36.7± 6.2	36.2 ± 5.8	37.2 ± 6.5	37.8± 7.3	39.2 ± 7.8	<.001
No CMCs	–	0.6 ± 0.5	1.4 ± 0.6	2.3 ± 0.5	3.7 ± 1.2	3.5 ± 1.4	<.001
Low Income (%)*	24.1	23.7	25.8	28.1	36.1	38.8	.190
No Insurance (%)	21.6	23.3	18.0	16.1	9.5	14.1	<.001
Physical inactivity (%)	59.9	58.1	59.0	59.7	70.0	63.5	<.001
Smoking (%)	13.5	13.1	14.7	14.9	11.7	21.2	.001
Alcohol use (%)	14.6	14.6	20.8	14.7	13.0	16.3	.072
Single MS (%)	43.5	36.6	45.3	21.5	18.6	29.7	<.001
LTHS Education (%)	15.2	16.7	18.8	25.4	33.0	27.4	.908
Poor self-rated health	11.3	15.4	22.5	29.5	31.9	35.3	.051
MEXICAN AMERICAN WOMEN							
Age (yr)	36.3 ± 9.6	39.9 ± 13.0	39.0 ± 12.6	53.8 ± 13.8	59.0 ± 12.0	50.2± 14.8	<.001
Weight (kg)	85.6±13.4	86.5 ± 14.4	88.4 ± 15.6	86.6 ± 13.7	87.5 ± 16.2	92.7± 18.1	<.001
Waist (cm)	106.0±9.8	107.5 ± 10.7	109.0 ± 11.5	108.9 ± 11.5	112.2 ± 12.4	112.8 ± 13.2	<.001
Body mass index	34.5 ±4.3	35.3± 4.8	35.6 ± 5.3	35.5 ± 4.8	36.3± 5.5	37.5 ± 6.4	<.001
No CMCs	–	0.5 ± 0.2	1.5 ± 0.6	2.4 ± 0.5	4.1 ± 1.1	3.6 ± 1.5	<.001
Low Income (%)*	19.1	21.1	27.6	30.2	36.6	33.1	<.001
No Insurance (%)	51.8	49.2	44.8	33.6	28.7	37.1	<.001
Physical inactivity (%)	59.6	60.1	64.2	66.1	71.3	62.4	.044
Smoking (%)	5.3	6.2	8.1	7.4	7.9	10.1	.657
Alcohol use (%)	16.4	13.9	10.3	12.8	7.9	9.4	.084
Single MS (%)	21.1	16.0	17.0	11.5	4.6	6.9	<.001
LTHS Education (%)	40.4	45.1	54.6	58.1	63.1	45.9	<.001
Poor self-rated health	8.2	12.8	16.0	17.0	17.9	21.6	.006

Table 4
Association between obesity clustering and overall self-rated health.

Variables	MEN						WOMEN					
	NHW		NHB		MA		NHW		NHB		MA	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Cluster												
Asymptomatic	1.00	Reference	1.00	Reference	1.00	Reference	1.00	Reference	1.00	Reference	1.00	Reference
1	1.21	0.76–1.91	1.05	0.56–1.96	1.84	0.89–3.79	1.03	0.70–1.51	1.18	0.78–1.80	1.36	0.79–2.31
2	1.62	1.01–2.60	1.24	0.67–2.30	2.41	1.11–5.25	1.24	0.84–1.82	1.26	0.79–2.01	1.21	0.69–2.11
3	2.17	1.41–3.36	1.83	1.01–3.35	2.78	1.37–5.65	1.75	1.20–2.57	1.81	1.16–2.84	1.22	0.66–2.19
4	2.51	1.55–4.07	1.78	0.72–3.44	2.47	0.99–6.17	2.61	1.77–3.86	2.52	1.58–4.02	2.05	1.02–4.14
5	3.88	2.41–6.26	3.96	1.86–8.30	7.25	2.41–9.61	4.08	2.71–6.14	4.01	2.40–6.69	2.62	1.32–5.19
Age	0.99	0.98–1.00	1.02	1.00–1.03	0.99	0.98–1.01	0.98	0.97–0.99	1.01	0.99–1.02	1.04	0.99–1.06
Income (<$20K)	1.66	1.28–2.17	1.33	0.93–1.93	1.85	1.24–2.79	1.96	1.55–2.47	1.19	0.91–1.55	1.13	0.75–1.72
No health insurance	1.31	0.99–1.74	1.19	0.85–1.67	1.12	1.06–2.95	1.01	0.76–1.34	1.12	0.82–1.51	1.77	1.22–2.58
Physical inactivity	1.58	1.22–2.04	0.92	0.71–1.20	1.21	0.80–1.57	1.23	1.03–1.46	0.87	0.68–1.09	1.49	1.08–2.07
Smoking	1.55	1.15–2.51	0.93	0.86–1.30	0.96	0.55–1.67	2.28	1.72–3.00	1.49	1.04–2.12	1.74	0.87–3.49
Alcohol intake	1.37	1.11–1.69	0.84	0.59–1.20	1.50	0.97–2.32	1.21	0.98–1.49	0.82	0.60–1.11	1.01	0.65–1.57
Not married	1.77	1.34–2.33	0.85	0.60–1.19	1.02	0.60–1.74	1.13	0.85–1.50	1.04	0.80–1.36	1.08	0.69–1.11
No high school ed	1.75	1.33–2.32	1.33	0.95–1.87	2.34	1.67–3.38	1.51	1.15–1.98	1.51	1.12–2.05	3.03	2.06–4.45

OR, Odds ratio from logistic regression analysis; CI, Confidence intervals; NHW, Non-Hispanic White; NHB, Non-Hispanic Black; MA, Mexican American.

insurance, physical inactivity, smoking, alcohol intake, marital status and education. The corresponding values for are 1.18, 1.26, 1.81, 4.01, and 1.35 for NHB women, and 1.21, 1.22, 2.19, 2.05 and 2.62 for MA women, respectively.

4. Discussion

Evidence of heterogeneity of obesity exists [34,35]. Indeed, Ogden et al. [36] used a cluster analysis to identify subgroups of obese individuals who were successful in maintaining weight loss. However, there has been relatively little consideration of the population level heterogeneity of obesity using other measures to explore their validity. Hence, in this study we used segmentation analysis to identify subgroups of obesity persons and investigate risk factors and comorbidities that are associated with the resulting cluster patterns. One of novelties of this study is that we tested cluster validity by assessing the relationship between cluster membership and participant's self-rated overall health. Self-rated health is a subjective reflection of health status, called "perceived" or "subjective" health that is a broad summary measure of different domains of health that include psychosocial domain [25,37]. Self-rated health is highly correlated with objective health status measures [38].

We found that approximately 4.5% and 8% of obese American men and women did not have any of the studied comorbidities. These asymptomatic obese participants were younger, had lower BMI, higher income, more physically active, unmarried and had better self-rated health compared to symptomatic participants. This study identified five distinct obesity phenotypes each in obese men and women. The identified obesity clusters showed varying degree of self-rated overall health and behavioral risk factors. We found syndemic obese elderly men and women to have mixed pattern of CMCs and behavioral characteristics than non-obese and other obese participants.

We found significant association between the cluster membership and behavioral risk factors of physical inactivity, low income and lack of high school education. The rate of poor self-rated overall health in these populations was tightly linked to obesity cluster membership, increasing with increasing number of CMCs. Compared to asymptomatic obese participants, and controlling for age, income, insurance, physical inactivity, smoking, alcohol intake, marital status and education, syndemic elderly obese men and women showed much greater odds of poor health compared to other study participants. We observed racial/ethnic differences in comorbidities in this study. Factors contributing to cluster assignment varied by sex and race/ethnicity. Our finding showing distinct obesity subgroups is consistent with previous studies indicating heterogeneity of obesity [34,35]. Using cluster analysis to explore subgroups of obese persons, Green et al., [34], found six distinct groups of individuals whose BMI was 30 kg/m^2 greater using behavioral variables. Similar to the result of this study, these authors found positive association between poor quality of life (determined using the EuroQoL EQ5D) and obesity cluster membership [34]. In another study, Ogden et al. [36] found that obesity cluster membership is associated with successful maintenance of weight loss in an intervention study.

The major strength of this study is the empirical nature of the segmentation method that was employed in this study. Cluster analysis is a multivariate method used to classify a sample of subjects (or objects) on the basis of a set of measured variables into a number of different groups such that similar subjects are placed in the same group. However, some limitations must be taken into account in the interpretation of results from this study. First, cluster analysis is a data-driven method, and the results may not be generalizable to other obese populations. Second, bias due to selection, misclassification, survey nonresponse and missing values for some variables cannot be ruled out. However, previous studies based on data from NHANES have shown little bias due to survey nonresponse. Third, results are based on some self-reported CMC symptoms and not actual disease processes, which might be influenced by reporting biases across individuals or groups. Fourth, as a cross section study, directionality of the associations between the obesity cluster membership and self-rated overall health cannot be clearly established as well as there are limitations of the statistical modeling techniques that were used.

The result of this study has some public health and clinical significance. Due to the many subgroups in this study it may be argued that the study is a mere categorization of those with more medical metabolic conditions as more problematic for targeting interventions. Indeed, it is logically that as one get older, one will have more chronic conditions. In actual situation, the severity of medical chronic conditions usually dictates the management of the patient. It is also logical for one to agree that those with more medical conditions have more problems with more high rates of behavioral risk factors and showed significantly greater odds of poor self-rated health. Obesity interventions targeting cluster membership may allow for a much more efficient targeting of scant healthcare and health promotion resources. For example, targeting of health promotion messages to NHB female with hypertension may require different interventions compared to NHB female with multiple CMCs. For clinicians, the recognition of different subtypes of obesity on the basis of comorbidities may help in dispensing appropriate treatments rather than treatments that are based solely on BMI status. The result of this study linking CMCs with poor self-rated health suggests that clustering of CMCs in obesity may be the trigger of unhealthy obesity phenotype; this warrants further investigations.

5. Conclusion

There are distinct subgroups of obese American men and women defined by varying cardiovascular and metabolic manifestations. A one size fit all approach to obesity prevention is unlikely to be effective. Obesity subgroup membership based on cardiovascular and metabolic manifestations could influence prognosis, treatment or intervention outcomes. The high degree of association between obesity subgroup membership and self-rated overall health suggests the need for a more comprehensive approach to the management of obesity with greater attention to the diagnosis of specific subtypes of obesity that will drive subsequent management of obese persons.

Compliance with ethical standards conflict of interest

The authors declare that they have no conflict of interest.

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