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ORIGINAL ARTICLE

Comparison of body mass index with waist circumference and skinfold-based percent body fat in firefighters: adiposity classification and associations with cardiovascular disease risk factors

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Abstract
Purpose This study aims to examine whether body mass index (BMI) overestimates the prevalence of overweight or obese firefighters when compared to waist circumference (WC) and skinfold-based percent body fat (PBF) and to investigate differential relationships of the three adiposity measures with other biological cardiovascular disease (CVD) risk factors.
Methods The adiposity of 355 (347 males and eight females) California firefighters was assessed using three different measures. Other CVD risk factors (high blood pressure, high lipid profiles, high glucose, and low VO_2 max) of the firefighters were also clinically assessed.
Results The prevalence of total overweight and obesity was significantly ($p < 0.01$) higher by BMI (80.4 %) than by WC (48.7 %) and by PBF (55.6 %) in male firefighters. In particular, the prevalence of overweight firefighters was much higher ($p < 0.01$) by BMI (57.3 %) than by WC (24.5 %) and PBF (38.3 %). 60–64 % of male firefighters who were assessed as normal weight by WC and PBF were misclassified as overweight by BMI. When overweight by BMI was defined as 27.5–29.9 kg/m^2 (vs. the standard definition of 25.0–29.9 kg/m^2), the agreement of the adiposity classification increased between BMI and other two adiposity measures. Obese firefighters had the highest CVD risk profiles across all three adiposity measures. Only when overweight by BMI was defined narrowly, overweight firefighters had substantially higher CVD risk profiles. Obesity and overweight were less prevalent in female and Asian male firefighters.
Conclusions BMI overestimated the prevalence of total overweight and obesity among male firefighters, compared to WC and skinfold-based PBF. Overweight by BMI needs to be more narrowly defined, or the prevalence of BMI-based overweight (27.5–29.9 kg/m^2) should be reported additionally for prevention of CVD among male firefighters.

Keywords California · Professional firefighters · Obesity · Overweight · Ethnicity · Gender

Introduction

Obesity is a well-documented risk factor for chronic diseases such as hypertension, coronary heart disease, osteoarthritis, dyslipidemia, type II diabetes, some cancers as well as increased mortality (Flegal et al. 2013; McGee and Diverse Populations Collaboration 2005; National Institute of Health (NIH) 1998; World Health Organization (WHO) 2000). The prevalence of obesity in the working population of the USA as in the general population has increased, particularly over the last three decades (Caban et al. 2005). Male firefighters are among the top three occupational groups with the highest obesity prevalence in the USA (Caban et al. 2005; Choi et al. 2011; Haddock et al. 2011). As a result, overweight and obesity is an important occupational health issue to be urgently addressed for the 1.1 million US firefighters (Haddock et al. 2011) who are at high risk of on-duty cardiovascular disease (CVD) mortality (Geibe et al. 2008; Kales et al. 2007) and musculoskeletal injuries (Jahnke et al. 2013; Poplin et al. 2012).

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Although body mass index (BMI) has been the most widely used adiposity measure at wellness and fitness (WEFIT) programs for firefighters across the nation (Clark et al. 2002; Donovan et al. 2009; Soteriades et al. 2005; Tsismenakis et al. 2009) as for other occupational groups (Alasagheirin et al. 2011; Caban et al. 2005; Escoto et al. 2010; Sieber et al. 2014), there has been a strong skepticism as to whether BMI is a valid measure for adiposity among firefighters (Choi et al. 2011; Haddock et al. 2011; Jitnarin et al. 2013; Poston et al. 2011) because of self-selection into the occupation and the possibility of building musculature through on-the-job physical training. Two assumptions underlying firefighter skepticism are: (1) BMI may overestimate the prevalence of overweight and obesity among firefighters because of its intrinsic inability to differentiate fat body mass and lean body mass and (2) other anthropometric adiposity measures such as waist circumference and skinfold-based percent body fat may be more strongly associated with biological CVD risk factors among firefighters than BMI (Choi et al. 2011).

Until recently, the concerns about BMI have not been tested empirically using multiple adiposity measures and biological CVD risk factors among professional firefighters. To the best of our knowledge, only one research group compared three anthropometric adiposity measures [BMI, waist circumference (WC), and foot-to-foot bioimpedance-based percent body fat (PBF-BIA-F)] among 478 male professional firefighters from the Missouri Valley region (Jitnarin et al. 2013; Poston et al. 2011) and recently among 994 male professional firefighters from 20 fire departments (Jitnarin et al. 2014; Poston et al. 2013) in the USA. They reported that the prevalence of obesity by BMI was lower (about 14–18 %) than by PBF-F, while it was similar to WC-based obesity prevalence (Jitnarin et al. 2014; Poston et al. 2011). However, they reported in another study with the Missouri Valley firefighters that BMI substantially overestimated the prevalence of "overweight" (defined as BMIs of 25.0–29.9 kg/m^2), compared to WC (a significant portion of firefighters were misclassified as overweight by BMI), while the prevalence of overweight by BMI was still lower than by PBF-F-based one (Jitnarin et al. 2013).

However, the findings of the aforementioned studies (Jitnarin et al. 2013, 2014; Poston et al. 2011) cannot be generalized until it is evaluated in more samples of US firefighters who have different backgrounds based on age, region, race/ethnicity, overweight and obesity prevalence, and WEFIT program. Also due attention should be paid to the possible overestimation of body fat by the PBF-F method that was used in the previous studies (Jitnarin et al. 2013, 2014; Poston et al. 2011), compared to the hydrodensitometry (hydrostatic weighing) or dual-energy X-ray absorptiometry (DXA) method in healthy non-obese and obese adults (Pateyjohns et al. 2006; Rutherford et al. 2011; Swartz et al. 2002). Using more accurate PBF methods may produce different results. Furthermore, another important question for prevention of obesity and CVD among firefighters remains unanswered in the previous studies (Jitnarin et al. 2013, 2014; Poston et al. 2011): whether the disagreement in defining overweight or obese firefighters between the three anthropometric adiposity measures, if any, will result in differential associations with standard biological CVD risk factors among firefighters.

The objectives of this study are (1) to examine whether BMI overestimates the prevalence of overweight or obesity among firefighters when compared to WC and skinfold PBF and (2) to compare the relationships of the three adiposity measures with several biological CVD risk factors in firefighters from Southern California who participated in the Firefighter Obesity Research: Workplace Assessment to Reduce Disease (FORWARD) study (Choi et al. 2011).

Methods

Background: FORWARD study

The main purpose of the FORWARD study (2010–2013) was to identify occupational and behavioral risk factors for obesity in firefighters who work for a fire department in Sothern California, USA (Choi et al. 2011, 2014; Dobson et al. 2013). The FORWARD study had strong support from both the fire department and a local union of the International Association of Fire Fighters (IAFF). It has been conducted as a joint project between university researchers and firefighters based on the principles of participatory research (Dollard et al. 2008; Greenwood et al. 1993). The FORWARD study was approved by the Institutional Review Board (IRB) of the University of California, Irvine. Phase I of the study involved developing a firefighter-specific work and health questionnaire through four focus groups with 20 firefighters from January to April 2011 (Choi et al. 2014; Dobson et al. 2013). Utilizing input from the focus groups, a 19-page firefighter-specific work and health questionnaire (called hereafter the FORWARD study questionnaire) was developed. Phase II of the study involved a cross-sectional survey using the FORWARD study questionnaire. All together 365 firefighters (356 males and nine females) participated in the survey (participation rate, 84 % of the 436 firefighters) when they visited the clinic for their wellness and fitness (WEFIT) medical examinations at a university clinic between May 2011 and December 2012.

Three measures of adiposity

The adiposity of the firefighters was assessed by an experienced exercise physiologist at their WEFIT medical

examinations based on standard assessment protocols for BMI (based on weight and height), WC, and PBF based on skinfold thickness. Firefighters wore light exercise clothing and took their shoes off to measure weight to the nearest 0.1 kg using a calibrated weight scale (Detecto D1130 mechanical weight scale). Height was measured to the nearest 0.1 cm using a clinical stadiometer (Seca 216). WC was measured to the nearest 0.1 cm in the horizontal plane of the superior border of the iliac crest as recommended by the National Cholesterol Education Program Adult Treatment Panel III (ATP-III) (Grundy et al. 2004), using an anthropometric fiberglass non-stretchable tape (Grafco). Skinfold thickness of three sites (abdomen, chest, and thigh for men; and triceps, suprailiac, and thigh for women) was measured twice at each site to the nearest 0.1 cm with a Lange skinfold caliper (Beta Technology Inc.) after daily calibration using a block of known width. When the two values of skinfold thickness were <0.1 cm of each other, the average of the two values was used for analysis. PBF was estimated using the gender-specific body density equations (Jackson and Pollock 1978; Jackson et al. 1980) and the Siri equation (Siri 1961). Among the 365 survey participants, 355 (347 males and eight females) firefighters had all information about the three adiposity measures.

Definitions of overweight and obesity by three adiposity measures

Obese firefighters were defined with each of the three adiposity measures based on the respective standard cut-points that have been recommended by the World Health Organization (WHO) or the American Council on Exercise (ACE): BMIs $\geq$ 30 kg/m^2 (World Health Organization (WHO) 2000); WCs of >102 cm (40 in.) for men and >88 cm (35 in.) for women (World Health Organization (WHO) 2000); and PBF of $\geq$25 % for men and $\geq$32 % for women (American Council on Exercise 2009). Overweight firefighters were defined based on the following criteria: BMIs of $\geq$25 and <30 kg/m^2 (World Health Organization (WHO) 2000), WCs of 94.1–102.0 cm ($\geq$37 and <40 in., called "waist action level 1") for men and of 80.1–88.0 cm ($\geq$32 and <35 in., called "waist action level 1") for women (Lean et al. 1998), and PBF of $\geq$18 and <25 % (called, "average or acceptable range") for men (Jitnarin et al. 2013) and $\geq$25 and <32 % (called, "average or acceptable range") for women (American Council on Exercise 2009).

In addition, one alternative definition of BMI-based overweight (BMIs of $\geq$27.5 and <30 kg/m^2) was tested in the current study mainly because a World Health Organization (WHO) Expert Consultation (2004) started to recommend 27.5 of BMI as a potential public action cut-point as well as the aforementioned well-known standard overweight and obesity cut-points (25 and 30, respectively) for facilitating an international comparison given the varying cut-points for overweight and obesity by country. On the other hand, the skinfold-based method could underestimate PBF by 1 % on average, when compared to the underwater weighing method (Clark et al. 1993; Fogelholm and van Marken Lichtenbelt 1997; Stout et al. 1994). Thus, alternative cut-points (1 % lower ones than the ACE ones) of PBF were used for defining overweight and obese firefighters.

Other biological CVD risk factors

Firefighter resting blood pressures were measured by experienced nurses at the WEFIT clinic with an aneroid sphygmometer (Welch Allyn CE0050) based on a standard assessment protocol (5-min rest in a sitting position). Blood pressure was measured twice consecutively with a time interval of 1 min and averaged for analysis. VO_2 max (maximum oxygen uptake), a cardiorespiratory fitness measure, of each firefighter was estimated by the experienced exercise physiologist based on the Gerkin treadmill test protocol. Firefighter blood tests for fasting serum lipid profiles [total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides] and glucose were conducted in other local laboratories within 2 weeks before and after their WEFIT examinations. The firefighters returned the laboratory results to the WEFIT clinic. For the current study, the clinical information on fasting blood lipid profile and glucose was extracted utilizing a standard data extraction form that was filled out by clinical staff at the WEFIT clinic. The information on medications due to heart problem, hypertension, hyperlipidemia and diabetes mellitus, and use of tobacco products was also extracted from a clinical questionnaire that firefighters fill out at their WEFIT examinations.

Blood pressure, lipid profile, and estimated VO_2 max were analyzed as both continuous and dichotomous variables. However, fasting glucose was analyzed only as a continuous variable because there were very few cases (<1 %) of diabetes mellitus in the firefighters. Hypertension was defined as systolic blood pressure $\geq$140 mmHg, $\geq$90 mmHg of diastolic blood pressure, or taking antihypertensive medications (Chobanian et al. 2003). Hypercholesterolemia was defined as total cholesterol $\geq$240 mg/dL (Grundy et al. 2004); low HDL cholesterol as HDL cholesterol <40 mg/dL (Grundy et al. 2004); high LDL cholesterol as LDL cholesterol $\geq$160 mg/dL (Grundy et al. 2004); and hypertriglyceridemia as triglycerides $\geq$200 mg/dL (Grundy et al. 2004); and low VO_2 max as estimated VO_2 max <42 mL/kg/min (Donovan et al. 2009).

Other variables

Age, sex, race/ethnicity, education, job title (rank-and-file firefighters, firefighter apparatus engineers, engineers, firefighter captains, and firefighter chiefs), and frequency of exercise (moderate or vigorous level of physical activity and more than 30 min) at fire station were assessed with questions in the FORWARD survey questionnaire.

Statistical analyses

The firefighters' sociodemographic characteristics and the distributions of the three adiposity measures by sociodemographic characteristics were examined with descriptive statistics. The correlations between the three adiposity measures were then examined by gender and race/ethnicity. Adiposity classification (normal weight, overweight, and obesity) with the three measures was compared to each other. The agreement percentage was defined among the firefighters as the number of the firefighters having the same adiposity classification between BMI and the other two adiposity measures (e.g., "obesity" by both BMI and WC). Kappa and weighted kappa ($Kappa_{weighted}$: agreement weights: 1 for the diagonal, 0.5 for the cells one off the diagonal, and 0 for the cells two off the diagonal) statistics were also used for the agreement of the adiposity classification (three by three tables). The sensitivity and specificity statistics of BMI-based obesity were examined against obesity by WC and PBF. The sensitivity and specificity statistics of BMI-based overweight were examined against overweight by WC or PBF only among normal or overweight firefighters for a consistent comparison with the previous study (Jitnarin et al. 2013). Lastly, Spearman's correlations of the three adiposity measures as continuous variables with the biological CVD risk factors as continuous variables were examined and compared. The prevalence ratios (PRs) of overweight and obesity by the three adiposity measures as categorical variables for the biological CVD risk factors as dichotomous variables were also examined and compared using log-binomial regression analyses.

Results

Sociodemographic and occupational characteristics of the 355 firefighters

The mean age of the 355 firefighters participating in the FORWARD study survey was 42.3 years. Most were males, white, and high school or some college graduates (see Table 1). Among the male firefighters, Asian firefighters were younger than non-Hispanic white and Hispanic firefighters (mean age 36.8 vs. 42.5 and 43.8 years, respectively). Rank-and-file firefighters (44.8 %) were most prevalent, followed by captains (27.4 %), engineers (24.8 %), and chiefs (2.5 %). There were three rookies and 13 firefighters whose job titles (e.g., medical director, training officer, investigator, etc.) were not able to be classified into the four major groups above. 13.2 % of the firefighters reported that they used tobacco products. 86.7 % of the firefighters reported that they did exercise (moderate or vigorous level of physical activity and more than 30 min) two or more times per week at fire stations. The eight female firefighters were ethnically non-Hispanic white or Asian.

The distributions of three adiposity measures by sociodemographic and occupational characteristics

The means of BMIs, WCs, and skinfold-based PBF were 27.7 kg/m^2, 95.4 cm, and 18.8 %, respectively, in 347 male firefighters and 24.5 kg/m^2, 83.4 cm, and 22.0 %, respectively, in eight female firefighters (Table 2). Controlling for age, the means of BMIs and WCs were significantly ($p < 0.10$) lower in Asian firefighters than in non-Hispanic whites and Hispanics: 26.4 kg/m^2 (vs. 27.7 and 28.4 kg/m^2) and 89.9 cm (vs. 95.8 and 95.9 cm), respectively. There was no significant difference in PBF between the three race/ethnic groups, although the mean of PBF was still lower in Asian firefighters.

The means of BMIs, WCs, and PBF were only slightly higher in the some college or high school graduates than in those graduating college or graduate school. Job title was associated with age in the firefighters: rank-and-file firefighters (mean age 37.0 years), engineers (44.2 years), captains (47.6 years), and chiefs (52.4 years). The WCs and PBF means were lowest in rank-and-file firefighters, followed by engineers, captains, and chiefs, respectively. The BMI means had a similar pattern except that they were slightly lower in engineers than in rank-and-file firefighters.

Correlations between three adiposity measures among the firefighters

As expected, the three adiposity measures were highly correlated with each other in 347 male firefighters (Table 2): BMI and WC ($r = 0.85$, $p < 0.001$); WC and PBF ($r = 0.81$, $p < 0.001$); and BMI and PBF ($r = 0.70$, $p < 0.001$). The respective correlations were 0.86, 0.82, and 0.71 for non-Hispanic whites; 0.79, 0.74, and 0.60 for Hispanics; and 0.85, 0.80, and 0.77 for Asians in the male firefighters. Weight was also significantly correlated with all three measures; the correlation of weight was highest with WC and lowest with PBF. Age was positively correlated with all three adiposity measures, while it was negatively correlated with height.

Table 1 Sociodemographic and occupational characteristics of the professional firefighters ($N = 355$)

Category	Subcategory	Percentage (%)
Age	25–34	24.2
M(SD) = 42.3 years (8.8)	35–44	21.0
	45–54	37.7
	55–63	7.0
Gender	Men	97.7
	Women	2.3
Race/ethnicity	Non-Hispanic white	79.7
	Hispanic	9.9
	Asian	5.1
	Native American/Pacific Islander	2.2
	Others/unreported	4.0
Education	Some college or high school	52.5
	College	43.8
	Graduate school	3.8
Job title	Rank-and-file firefighters	44.8
	Firefighter apparatus engineers	24.8
	Firefighter captains	27.4
	Firefighter chiefs	2.9
	Others	4.5
Medication	No	83.9
	Yes (due to heart problems, high blood pressure, hyperlipidemia, or diabetes mellitus)	16.1
Use of tobacco products	No	86.8
	Yes	13.2
Exercise at fire station	0–1 times per week	13.3
	≥2 time per week	86.8

M mean, *SD* standard deviation

Table 2 Spearman's rank correlations between three adiposity measures in 355 firefighters

Sex	Mean (SD)	BMI	WC	PBF	Weight	Height
Men ($N = 347$)						
BMI (kg/m^2)	27.7 (3.13)					
WC (cm)	95.4 (9.32)	0.85**				
PBF (%)	18.8 (6.08)	0.70**	0.81**			
Weight (kg)	89.5 (11.97)	0.83**	0.86**	0.62**		
Height (cm)	179.6 (6.65)	−0.06	0.22**	0.04	0.50**	
Age (years)	42.4 (8.82)	0.21**	0.31**	0.47**	0.12*	−0.11*
Women ($N = 8$)						
BMI (kg/m^2)	24.5 (4.00)					
WC (cm)	83.4 (11.18)	0.95**				
PBF (%)	22.0 (5.30)	0.82*	0.73*			
Weight (kg)	71.6 (12.84)	0.96**	0.98**	0.77*		
Height (cm)	170.5 (4.92)	0.21	0.43	0.10	0.48	
Age (years)	38.8 (7.83)	−0.58	−0.47	−0.40	−0.46	0.20

BMI body mass index, *WC* waist circumference, *PBF* skinfold-based percent body fat

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

Table 3 Prevalence of overweight and obesity by three different adiposity measures in 355 firefighters (347 males and eight females)

Sex	Adiposity status	Body mass index		Waist circumference		Percent body fat		Percent body fat	
		Level (kg/m^2)	Prevalence (*N*)	Level (cm)	Prevalence (*N*)	Level (%)	Prevalence (*N*)	Level (%)	Prevalence
Men	Normal weight	18.5–24.9	19.6 % (68)	≤94	51.3 % (178)	<18	44.4 % (154)	<17	40.3 % (140)
	Overweight	25.0–29.9	57.3 % (199)	94.1–102.0	24.5 % (85)*	18–24.9	38.3 % (133)*	17–23.9	39.2 % (136)*
		25.0–27.4	33.7 % (117)						
		27.5–29.9	23.6 % (82)						
	Obesity	≥30.0	23.1 % (80)	>102	24.2 % (84)	≥25	17.3 % (60)	≥24	20.5 % (71)
Women	Normal weight	18.5–24.9	75.0 % (6)	≤80	62.5 % (5)	<25	87.5 % (7)	<24	75.0 % (6)
	Overweight	25.0–29.9	12.5 % (1)	80.1–88.0	25.0 % (2)	25–31.9	0.0 % (0)	24–30.9	12.5 % (1)
		25.0–27.4	12.5 % (1)						
		27.5–29.9	0.0 % (0)						
	Obesity	≥30.0	12.5 % (1)	>88	12.5 % (1)	≥32	12.5 % (1)	≥31	12.5 % (1)

* $p < 0.01$ at a Chi-square test with the BMI-based overweight percentage

In eight female firefighters, the three adiposity measures were highly correlated with each other as in male firefighters. However, the correlation pattern in the female firefighters appeared to be slightly different. The correlations of BMIs with the other two adiposity measures were higher, while the correlation between WC and PBF was lower in female firefighters than in male firefighters (Table 2). In addition, age was negatively associated with all three adiposity measures in eight female firefighters.

Obesity and overweight prevalence

The prevalence of total overweight and obesity varied significantly ($p < 0.01$) by specific adiposity measure in male firefighters: 48.7 % (by WC), 55.6 % (by PBF), and 80.4 % (by BMI) (Table 3). Obesity prevalence was highest by WC (24.2 %), followed by BMI (23.1 %) and PBF (17.3 %). Some firefighters (2.3 %) had >35 kg/m^2 of BMI (class II obesity). When the alternative PBF cut-point (>24 %) was applied, the prevalence of obesity increased to 20.5 % (closer to, albeit still lower than, the prevalence by BMI or WC). There was a significant ($p < 0.01$) variation in overweight prevalence between the adiposity measures: 24.5 % (by WC), 38.3 % (by PBF), and 57.3 % (by BMI) in the total sample (Table 3) and in each ethnic group (Fig. 1). The alternative PBF cut-point did not change much the prevalence of PBF-based overweight. However, when the alternative BMI-based overweight (27.5–29.9 kg/m^2) was applied, the prevalence of overweight by BMIs significantly decreased from 57.3 to 23.6 %, closer to the WC- or PBF-based one. The prevalence of combined overweight and obesity varied by specific adiposity measure in female firefighters: 12.5–25.0 % (by PBF), 25.5 % (by BMI), and 37.5 % (by WC) (Table 3). Obesity prevalence was 12.5 % by all three adiposity measures in eight female firefighters. Overweight prevalence ranged from 0.0 % (by PBF) to 25.0 % (by WC) in the eight female firefighters.

Agreements of the adiposity classification by BMI against WC and PBF

In male firefighters, the agreement percentage of the adiposity classification (normal weight, overweight, and obesity) was 56 % (Kappa 0.38 and Kappa$_{weighted}$ 0.48) between BMI and WC and 55 % (Kappa 0.30 and Kappa$_{weighted}$ 0.39) between BMI and PBF (Table 4A, C). However, when overweight was defined as BMIs of 27.5–29.9 kg/m^2, the agreement percentage substantially increased to 74 % (Kappa 0.57 and Kappa$_{weighted}$ 0.66) between BMI and WC and slightly increased to 60 % (Kappa 0.37 and Kappa$_{weighted}$ 0.47) between BMI and WC (Table 4B, D). The agreement percentage was 56 % (Kappa 0.32) between BMI and PBF with the alternative cut-points for overweight and obesity and 58 % (Kappa 0.35) between BMI (when overweight was narrowly defined) and PBF with the alternative cut-points. The results were very similar when the analyses were restricted to only white male firefighters.

The sensitivities of BMI-based obesity against obesity by WC and PBF were lower than its specificities: 0.65–0.73 versus 0.86–0.91. In other words, 27–35 % of the firefighters who were obese by WC and PBF were misclassified as non-obese firefighters by BMI (false negatives), while 9–14 % of the firefighters who were non-obese by WC and PBF were misclassified as obese by BMI (false positives). Among the normal or overweight male firefighters after excluding obese firefighters, the sensitivities of BMI-based obesity against obesity by WC and PBF were significantly higher than its specificities: 0.91–0.97 versus 0.38–0.40. In other words, 7–9 % of the firefighters who were overweight

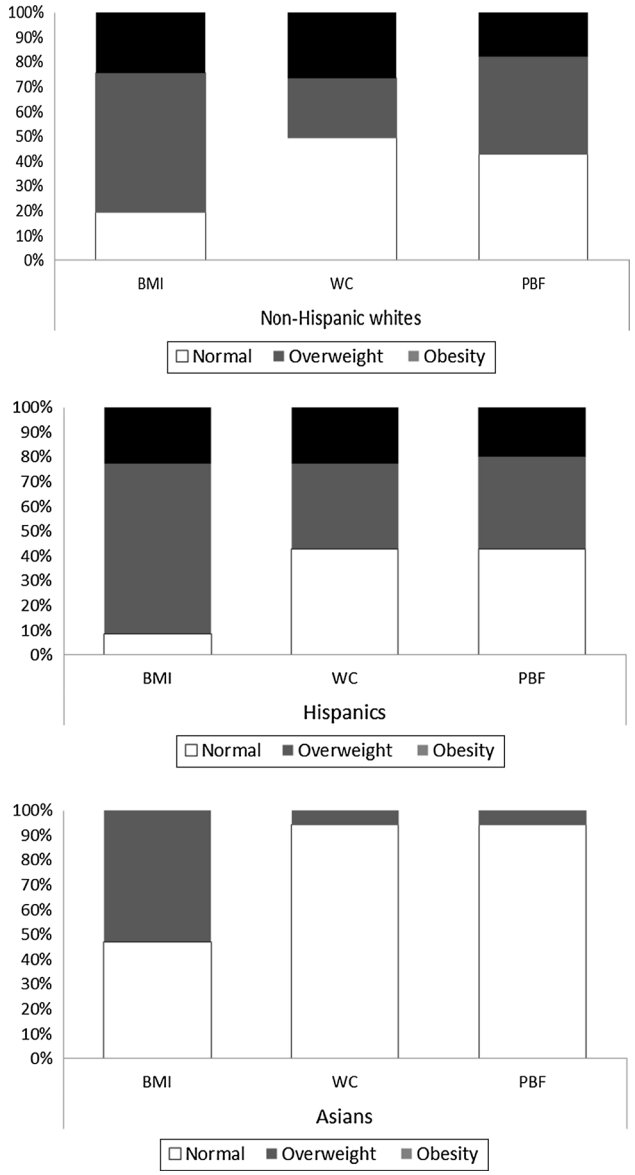

Fig. 1 Comparison of the adiposity classification (normal, overweight, and obese) of firefighters by three adiposity measures (*BMI* body mass index, *WC* waist circumference, *PBF* percent body fat) in male firefighters (non-Hispanic whites, $N = 275$; Hispanics, $N = 35$; and Asians, $N = 17$). The adiposity classification by BMI was significantly ($p < 0.01$) different from that by WC and by PBF

by WC and PBF were misclassified as normal-weight firefighters by BMI (false negatives), while 60–62 % of the firefighters who were normal weight by WC and PBF were misclassified as overweight by BMI (false positives). The low specificities of BMI-based overweight substantially increased to 0.87 (vs. 0.38) when overweight was defined as BMIs of 27.5–29.9 kg/m^2, while the sensitivity decreased (from 0.97 to 0.61). A similar pattern of change in the specificities and sensitivities of BMI-based overweight against PBF was observed (Table 4C, D).

Associations between three adiposity measures and other cardiovascular disease risk factors as continuous variables

In male firefighters, all three adiposity measures as continuous variables were significantly associated with the eight cardiovascular disease risk factors (Table 5). The associations with systolic and diastolic blood pressure, triglycerides, and fasting glucose were generally similar across the three obesity measures. WC was relatively strongly associated with HDL in comparison with BMI and PBF, while it was relatively weakly associated with total cholesterol. PBF was relatively strongly associated with LDL and VO_2 max.

The correlations varied by race/ethnicity to some extent. For example, the correlations of the adiposity measures with blood pressure and LDL were higher in Hispanic firefighters. By contrast, the correlations with fasting glucose appeared to be lower in Hispanic firefighters. On the other hand, the correlations of the adiposity measures with blood pressure and fasting glucose were higher in Asian firefighters.

Associations between three adiposity measures and other cardiovascular disease risk factors as categorical variables

The prevalence rates of hypertension, high cholesterol, low HDL, high LDL, high triglycerides, and low VO_2 max among the male firefighters were 11.0, 21.0, 21.4, 22.4, 25.8, and 31.9 %, respectively. In general, compared to the firefighters with normal adiposity, overweight and obese firefighters had worse CVD risk factor profiles (Table 6). As expected, the CVD risk factors were generally highest in obese firefighters than in normal or overweight firefighters across all three adiposity measures. Overweight firefighters by WC and PBF had significantly higher CVD risk factors than firefighters having the normal ranges of WC and PBF. The CVD risk factors were at least two times higher in WC-based overweight firefighters and 3.5 times higher in PBF-based overweight firefighters.

However, there were no significant differences in all CVD risk factors except for low VO_2 max between BMI-based normal-weight and overweight (BMIs of 25.0–29.9 kg/m^2) firefighters, although the CVD risk factors were 1.5–2.0 times higher in the BMI-based overweight groups than in the normal-weight group. When overweight firefighters were defined by the range of BMIs (27.5–29.9 kg/m^2), overweight firefighters had significantly higher prevalence of three out of the six CVD risk factors (high cholesterol, high LDL, and low VO_2 max) than firefighter having the normal ranges of BMIs. In contrast, there was no significant difference in all of the six

Table 4 Comparison of the adiposity classification (normal weight, overweight, and obesity) between BMIs and waist circumferences (WC) [A and B; the reference, WC] and between BMI and percent body fat (PBF) [C and D; the reference, PBF] in 347 male firefighters

[A]	WC normal	WC overweight	WC obesity	Total	Agreement = 56.2 % (Kappa .38[a])
BMI normal	66	2	0	68	Obesity sensitivity = .73 (61/84)
BMI overweight	108	68	23	199	Obesity specificity = .93 (244/263)
BMI obesity	4	15	61	80	Overweight[b] sensitivity = .97 (68/70)
Total	178	85	84	347	Overweight[b] specificity = .38 (66/174)
[B]	WC normal	WC overweight	WC obesity	Total	Agreement = 73.8 % (Kappa .57[a])
BMI 18.5–27.4	152	27	6	185	Obesity sensitivity = .73
BMI 27.5–29.9	22	43	17	82	Obesity specificity = .93
BMI 30 or more	4	15	61	80	Overweight[b] sensitivity = .61 (43/70)
Total	178	85	84	347	Overweight[b] specificity = .87 (152/174)
[C]	PBF normal	PBF overweight	PBF obesity	Total	Agreement = 54.5 % (Kappa = .30[a])
BMI normal	59	9	0	68	Obesity sensitivity = .65 (39/60)
BMI overweight	87	91	21	199	Obesity specificity = .86 (246/287)
BMI obesity	8	33	39	80	Overweight[b] sensitivity = .91(91/100)
Total	154	133	60	347	Overweight[b] specificity = .40 (59/146)
[D]	PBF normal	PBF overweight	PBF obesity	Total	Agreement = 60.2 % (Kappa = .37[a])
BMI 18.5–24.9	125	55	5	185	Obesity sensitivity = .65
BMI 27.5–29.9	21	45	16	82	Obesity specificity = .86
BMI 30 or more	8	33	39	80	Overweight[b] sensitivity = .45 (45/100)
Total	154	133	60	347	Overweight[b] specificity = .86 (125/146)

[a] Weighted kappas were .48, .66, .39, and .47, respectively. All kappas were significant ($p < 0.05$)

[b] Overweight sensitivity and specificity were calculated only with normal or overweight firefighters

CVD risk factors between BMI-based normal and overweight (defined as BMIs of 25.0–27.4 kg/m^2) firefighters. In particular, there was little difference in hypertension, high LDL, and high triglycerides between the two groups (Table 6): the PRs <1.30. On the other hand, the alternative PBF cut-points for overweight and obesity were as discriminant for the CVD risk factors as the standard PBF cut-points. The results were very similar when the analyses were restricted to only white male firefighters.

Discussion

In this study, BMI overestimated the prevalence of combined overweight and obesity by at least 25 %, compared to WC and skinfold-based PBF in male professional firefighters from Southern California. In particular, the prevalence of overweight was much higher by BMI (57.3 %) than by WC (24.5 %) and PBF (38.3 %) in male firefighters. Sixty and sixty-four percentages of male firefighters who were assessed as normal weight by WC and PBF, respectively, were misclassified as overweight by BMI (false positives). When overweight by BMI was defined narrowly as 27.5–29.9 kg/m^2 (vs. 25.0–29.9 kg/m^2), the agreement levels of the adiposity classification between BMI and WC and between BMI and PBF increased. Obese firefighters had the highest CVD risk profiles across all three adiposity measures. BMI-based overweight firefighters had only marginally higher CVD risk profiles, but when overweight by BMI was defined narrowly, overweight firefighters had substantially higher CVD risk profiles.

Comparison with previous studies

The current study from Southern California and the previous studies (Jitnarin et al. 2013, 2014) from other regions in the USA are consistent in that the prevalence of obesity was similar among male firefighters whether it was measured by BMI or WC. However, this is different from the result of US adult general population-based studies in which the prevalence of obesity was about 10 % higher by WC than by BMI in non-Hispanic whites (Ford et al. 2014; Freedman and Ford 2015; Ogden et al. 2014). In addition, the correlations between BMI and WC were weaker in the US firefighters of the current study and the previous studies (Jitnarin et al. 2013, 2014) than in US adult general populations (Freedman and Ford 2015): 0.74–0.85 versus 0.92–0.94, respectively. These suggest that the relationship

Table 5 Spearman's rank correlations between three adiposity measures and other cardiovascular disease risk factors in 347 male firefighters

Other CVD risk factors	In 347 male firefighters				In 35 Hispanics (Ns, 28–35)				In 17 Asians (Ns, 13–17)			
	Mean (SD)	BMI	WC	PBF	Mean (SD)	BMI	WC	PBF	Mean (SD)	BMI	WC	PBF
Systolic blood pressure ($N = 345$): mmHg	112.4 (11.6)	0.25***	0.22***	0.21***	113.2 (10.5)	0.46**	0.40*	0.37*	108.1 (8.9)	0.59*	0.55*	0.71**
Diastolic blood pressure ($N = 345$): mmHg	76.2 (7.5)	0.31***	0.29***	0.31***	75.3 (7.6)	0.43*	0.54**	0.67***	75.1 (8.0)	0.38	0.47	0.53*
Total cholesterol ($N = 295$): mg/dL	190.7 (35.1)	0.18**	0.14*	0.20**	197.2 (38.1)	0.34	0.14	0.18	191.1 (28.3)	0.12	0.16	0.20
HDL ($N = 295$): mg/dL	54.3 (12.9)	−0.33***	−0.43***	−0.38***	53.9 (11.8)	−0.06	−0.18	−0.19	50.9 (9.6)	−0.37	−0.30	−0.06
LDL ($N = 295$): mg/dL	114.3 (30.9)	0.19**	0.18**	0.25***	119.0 (27.9)	0.46*	0.26	0.44*	119.9 (25.6)	−0.09	0.04	−0.08
Triglycerides ($N = 295$): mg/dL	109.3 (76.8)	0.46***	0.49***	0.46***	121.5 (83.4)	0.47*	0.44*	0.18	101.9 (66.0)	0.67**	0.58*	0.53*
Fasting glucose ($N = 295$): mg/dL	93.63 (18.9)	0.24***	0.26***	0.26***	93.66 (7.1)	0.09	−0.002	0.10	92.1 (9.2)	0.79**	0.76**	0.56*
VO_2 max ($N = 323$): mL/kg/min	46.2 (7.1)	−0.41***	−0.47***	−0.60***	46.9 (7.0)	−0.42*	−0.32	−0.64***	49.3 (5.8)	−0.60*	−0.50	−0.61*

BMI body mass index, *WC* waist circumference, *PBF* skinfold-based percent body fat

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 6 Prevalence (prevalence ratio) of each of the six cardiovascular disease (CVD) risk factors by adiposity classification of the three adiposity measures in 347 male firefighters

Adiposity measure	Adiposity classification	Level[a]	Hypertension ($N = 345$)	High cholesterol ($N = 345$)	Low HDL ($N = 295$)	High LDL ($N = 295$)	High triglycerides ($N = 295$)	Low VO_2 max ($N = 323$)
BMI (kg/m^2)	Normal weight	18.5–24.9	5.9 (1.00)	10.3 (1.00)	8.6 (1.00)	12.1 (1.00)	8.6 (1.00)	15.6 (1.00)
	Overweight	25.0–29.9	9.6 (1.64)	19.8 (1.91)	16.9 (1.96)	20.3 (1.69)	14.0 (1.62)	29.0 (1.86)*
		25.0–27.4	6.9 (1.17)	15.4 (1.49)	14.4 (1.67)	15.4 (1.28)	8.7 (1.00)	20.0 (1.28)
		27.5–29.9	13.6 (2.31)	26.5 (2.56)*	20.6 (2.39)	27.9 (2.32)*	22.1 (2.56)	42.1 (2.70)**
	Obesity	≥30	21.3 (3.61)*	33.3 (3.22)**	43.5 (5.04)***	34.8 (2.88)**	36.2 (4.20)**	53.4 (3.42)***
WC (cm)	Normal weight	≤94.0	6.8 (1.00)	13.4 (1.00)	8.4 (1.00)	13.5 (1.00)	7.1 (1.00)	15.0 (1.00)
	Overweight	94.1–102.0	14.1 (2.07)	32.4 (2.39)**	29.6 (3.53)***	35.2 (2.60)***	29.6 (4.17)***	45.7 (3.05)***
	Obesity	≥102	19.0 (2.79)**	26.0 (1.92)*	41.1 (4.90)***	27.4 (2.02)*	30.1 (4.25)***	54.7 (3.65)***
PBF (%)	Normal weight	<18.0	3.9 (1.00)	6.9 (1.00)	5.4 (1.00)	7.7 (1.00)	2.3 (1.00)	9.5 (1.00)
	Overweight	18.0–24.9	13.6 (3.48)**	30.2 (4.36)***	29.3 (5.44)***	30.2 (3.92)***	26.7 (11.58)***	43.4 (4.56)***
	Obesity	≥25	26.7 (6.80)***	35.8 (5.18)***	43.4 (8.06)***	39.6 (5.15)***	37.7 (16.35)***	66.7 (7.00)***
PBF (%)	Normal weight	<17.0	2.9 (1.00)	5.9 (1.00)	5.9 (1.00)	6.8 (1.00)	2.5 (1.00)	6.7 (1.00)
	Overweight	17.0–23.9	14.1 (4.89)**	28.8 (4.86)***	26.3 (4.43)***	28.8 (4.25)***	23.7 (9.33)***	40.7 (6.10)***
	Obesity	≥24	23.9 (8.32)***	34.9 (5.89)***	41.3 (6.96)***	38.1 (5.62)***	36.5 (14.36)***	67.7 (10.15)***

Hypertension was defined as systolic blood pressure ≥140 mmHg, ≥90 mmHg of diastolic blood pressure, or taking anti-hypertensive medications. Hypercholesterolemia was defined as total cholesterol ≥240 mg/dL; low HDL cholesterol as HDL cholesterol <40 mg/dL; high LDL cholesterol as LDL cholesterol ≥160 mg/dL; hypertriglyceridemia as triglycerides ≥200 mg/dL; and low VO_2 max as VO_2 max <42 mL/kg/min

BMI body mass index, *WC* waist circumference, *PBF* skinfold-based percent body fat

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[a] See Table 3 for the number of the firefighters in each level

between BMI and WC may differ between US firefighters and US general populations.

The current study was also consistent with the previous studies in firefighters in that the prevalence of "overweight" was substantially higher by BMI than by WC and as a result, the prevalence of combined overweight and obesity was higher by BMI than by WC. In addition, while the prevalence of obesity by BMI was similar between the current study from Southern California and California adult general population, the prevalence of overweight by BMI (25.0–29.9 kg/m^2) was much higher in the current study than California adult general population from the Behavioral Risk Factor Surveillance System (BRFSS) surveys 2011–2012 (57.3 vs. 35.3–36.4 %). All these, along with the relatively weak associations between BMI-based overweight and CVD risk factors, indicate more misclassified overweight cases by BMI in firefighters than in general adult populations.

With regard to BMI and PBF, the results of the current study were opposite to those of the previous studies. In the current study, the prevalence of overweight and obesity was much higher by BMI than by PBF; however, in the previous studies (Jitnarin et al. 2013, 2014; Poston et al. 2011), it was the opposite. The method of estimating body fat differed between the current study (skinfold-based) and the previous studies (foot-to-foot bioimpedance-based, using the Tanita 300, Tanita Corporation Inc.), which makes a direct comparison between the current and previous studies difficult. Nonetheless, it should be considered that in several studies (Pateyjohns et al. 2006; Rutherford et al. 2011; Swartz et al. 2002), PBF-BIA-F assessed using the Tanita 300 series [as used in the previous studies (Jitnarin et al. 2013, 2014; Poston et al. 2011)] overestimated body fat by on average, 1–5 %. In the current study, we made efforts to assess PBF more accurately using rigorous procedures (using a standard protocol, average score of two time assessments at each skin site for analysis, done by an experienced expert at a clinic) and an additional sensitivity test under the assumption of a possible underestimation of body fat by the skinfold-based method.

On the other hand, it needs to be emphasized that compared to the male firefighters in the previous studies from other states and regions (Jitnarin et al. 2013, 2014; Poston et al. 2011), the male professional firefighters in the current study from Southern California were lighter (mean BMI 27.6 vs. 28.6 kg/m^2; mean WC 95.3 vs. 97.3 cm; and mean PBF 18.8 vs. 23.2–25.3 %). The prevalence of obesity by BMI (23.1 %) among male professional firefighters in the current study was also lower than in the previous studies with firefighters (30.0–33.5 %) from the US Missouri Valley states and other regions (Jitnarin et al. 2013, 2014; Poston et al. 2011), and also in the

US adult population (34.9 %) from the National Health and Nutrition Examination Survey, 2011–2012 (Ogden et al. 2014). However, it was about the same as the prevalence of obesity by self-reported BMI (23.8–25.0 %) in the California adult population from the BRFSS surveys 2011–2012. The regional variation among the US states is quite well-known (Le et al. 2014): Most of the US Missouri Valley states in the previous study (Poston et al. 2011) are among the heaviest states, while California is a relatively leaner state. Also it is noteworthy that a good WEFIT program has been successfully implemented in the fire department of the current study since 2004. The prevalence of obesity was much lower in fire departments having a good WEFIT program than in fire departments without a WEFIT program: 25.3 versus 35.6 % by BMI (Poston et al. 2013).

The prevalence of combined overweight and obesity was lower among female firefighters than among male firefighters, which is consistent with the previous studies (Caban et al. 2005; Jahnke et al. 2012). Future studies are needed to explore the reasons for the gender difference. Consistent with national statistics (Ogden et al. 2014), firefighters with an Asian ethnic background had the lowest prevalence of overweight and obesity among male firefighters.

However, the correlations of the adiposity measures with blood pressure and fasting glucose were higher in Asian firefighters. This was generally consistent with the existing literature on the higher associations of BMI with hypertension (Colin Bell et al. 2002; Katz et al. 2013) and diabetes mellitus (Shai et al. 2006) in Chinese adults than in Caucasian adults. The correlations of the adiposity measures with blood pressure and LDL were higher in Hispanic firefighters, while the correlations with fasting glucose were lower in Hispanic firefighters. However, the correlation between BMI and blood pressure was similar between non-Hispanic white and Mexican Americans in a US national survey (Brown et al. 2000).

In the current study, the associations between BMI-based overweight (25.0–27.4 kg/m^2) and CVD risk were weak (PRs 1.00–1.67, compared to the BMI normal-weight group), while the associations between BMI-based overweight (27.5–29.9 kg/m^2) and CVD risk factors were relatively strong (PRs 2.31–2.70). The agreement of the adiposity classification between BMI and the other adiposity measures also increased when overweight by BMI was defined as BMIs of 27.5–29.9 kg/^{2} than 25.0–29.9 kg/m^2. Furthermore, some investigators (Pischon et al. 2008) have reported that BMI started to increase the risk of CVD mortality only when BMI reached 28.0 kg/m^2 in a large European cohort study. All these cast a doubt to the validity of the standard definition of BMI-based overweight as 25.0–29.9 kg/m^2 as a way to identify a group of firefighters having a high risk of CVD. At least, this study supports reporting the prevalence of BMI-based overweight (27.5–29.9 kg/m^2) as well as the prevalence of the standard BMI-based overweight in US firefighters, which is in line with the new recommendation of a World Health Organization (WHO) Expert Consultation (2004): reporting BMI-based prevalence based on all standard cut-points and the new public health action points.

Important implications for prevention of CVD among firefighters and other workers

The current standards of the National Fire Protection Agency (NFPA) for comprehensive occupational medical program (standard 1582) (National Fire Protection Agency 2013) and health-related fitness program (standard 1583) (National Fire Protection Agency 2015) for firefighters and the Fire Service Joint Labor Management Wellness–Fitness Initiative (International Association of Fire Chiefs and International Association of Fire Fighters 2008) all recommend annual evaluation of body composition as a part of the fitness assessment of individual firefighters. Although the NFPA standards suggested BMI as an "optional" measure of several body composition measures (skinfold-based PBF, circumferences, and bioimpedance), BMI is the most widely used adiposity measure at firefighter WEFIT programs in the USA (Clark et al. 2002; Donovan et al. 2009; Soteriades et al. 2005; Tsismenakis et al. 2009) and there are no specific instructions for the use of BMI as an optional measure for firefighters.

When BMI is the only available measure, BMI-based overweight among male professional firefighters needs to be more narrowly defined (27.5–29.9 kg/m^2) or the prevalence of the BMI-based overweight (27.5–29.9 kg/m^2) needs to be additionally reported, due to the problems with the standard BMI-based overweight (25.0–29.9 kg/m^2): overestimated overweight prevalence, high false positives of overweight firefighters, and nonsignificant associations with other CVD risk factors. Also, whenever possible, it would be better to analyze BMI as a continuous rather than categorical variable, given the similar correlations of all three adiposity measures as continuous variables with CVD risk factors in the current study. Furthermore, this study indicates the need for more studies to compare several adiposity measures (e.g., BMI, skinfold-based PBF, and BIA-based PBF against the hydrodensitometry or DXA method) among firefighters that will strengthen the current NFPA standards.

BMI is intrinsically blind to the difference between fat body mass and lean body mass. In addition, the association between BMI and body fat differs by age (e.g., the elder) and race/ethnicity (e.g., African-Americans) (Deurenberg et al. 1998; Jackson et al. 2002, 2009; Prentice and Jebb

2001) as well as occupation (e.g., athletes, firefighters, and policemen). Nonetheless, BMI is the most widely used adiposity measure in most occupational wellness programs for working populations in the USA. Given the aging and racially/ethnically diversifying workforce in the USA (Toossi 2012), more studies comparing and using multiple adiposity measures in diverse populations are needed.

Lastly, we emphasize that at least one in two male firefighters in the current study had a level of adiposity significantly associated with most CVD risk factors (high blood pressure, high lipid profiles, and low VO_2 max) across all three adiposity measures. In addition, one in three male firefighters in the current study did not meet a generally accepted minimum cardiorespiratory fitness level of 42.0 mL/kg/min for firefighters (Donovan et al. 2009; National Fire Protection Agency 2013; Sothmann et al. 1992), even though the VO_2 max values may have been overestimated due to the use of the Gerkin submaximal test (Mier and Gibson 2004). These findings are alarming given that the fire department of the current study has one of the strongest and long-lasting WEFIT programs among US fire departments.

Some investigators (Carey et al. 2011; Elliot et al. 2007; Winick et al. 2002) have reported short-term (<6 months) beneficial effects of health promotion programs on the weight and BMI of firefighters. However, the initial program effects did not last long after the completion of the programs (MacKinnon et al. 2010; Ranby et al. 2011; Winick et al. 2002). It is important to continuously support firefighter peer fitness certification programs (International Association of Fire Chiefs and International Association of Fire Fighters 2008). In addition, the role of the peer fitness trainers should be expanded to including nutrition and stress management as well as physical fitness, given the current unhealthy eating cultures (Dobson et al. 2013; Haddock et al. 2011) and stressful working conditions of firefighters (Choi et al. 2011; Dobson et al. 2013; Guidotti 1992; Kales et al. 2009). Furthermore, we think that several obesogenic working conditions identified in the FORWARD study such as too many 24-h shifts, sedentary work, and low supervisor and management support (Choi et al. 2011; Choi 2014; Dobson et al. 2013) should be addressed in addition to efforts to enhance health promoting behaviors of firefighters. This would provide a more sustainable and comprehensive worksite health promotion program for the prevention of obesity and CVD among firefighters.

Limitations

There are several limitations in this study. First, the results in the current study came from a group of firefighters who work for a fire department in Southern California. Thus, the results should be tested and confirmed in future studies with different samples of firefighters. However, this is the first study providing empirical evidence that supports the strong skepticism among US firefighters about BMI as a valid adiposity measure for firefighters and also suggests an alternative definition of BMI-based overweight (27.5–30 kg/m^2) among firefighters. Second, it should be emphasized that the differential relationships between three adiposity measures and other CVD risk factors were cross-sectional. Thus, the results should be reexamined in the future with longitudinal data. However, several investigators (Abell et al. 2007; Flegal et al. 2013; McGee and Diverse Populations Collaboration 2005; Pischon et al. 2008) in longitudinal population-based studies have also reported no significant or a marginally significant association between the standard BMI-based overweight and CVD mortality. Third, in this study, body fat information based on the hydrodensitometry or DXA methods, known as a more accurate adiposity measures than the skinfold PBF, was not available. However, we think that the measurement errors in our skinfold PBF data in the current study would be small if any, due to the methodological rigor of our procedures. Also our sensitivity tests using the lower skinfold-based PBF cut-points did not change the results substantially. Fourth, the differential associations between the adiposity measures and other CVD risk factors by gender and ethnicity in the current study should be tested and confirmed in future studies with a larger sample of female and minority firefighters.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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