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BMI and obesity in US blood donors: a potential public health role for the blood centre

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Abstract

Objective: According to the 2007–2008 National Health and Nutrition Examination Survey, the prevalence of obesity in the US population was 33·8 %; 34·3 % and 38·2 %, respectively, in middle-aged men and women. We asked whether available blood donor data could be used for obesity surveillance.
Design: Cross-sectional study of BMI and obesity, defined as BMI $\geq 30\cdot0\,kg/m^2$. Adjusted odds ratios (aOR) were calculated with logistic regression.
Setting: A network of six US blood centres.
Subjects: Existing data on self-reported height and weight from blood donors, excluding persons deferred for very low body weight.
Results: Among 1 042 817 donors between January 2007 and December 2008, the prevalence of obesity was 25·1 %; 25·7 % in men and 24·4 % in women. Obesity was associated with middle age (age 50–59 years *v.* <20 years: aOR = 1·92 for men and 1·81 for women), black (aOR = 1·57 for men and 2·35 for women) and Hispanic (aOR = 1·47 for men and 1·49 for women) race/ethnicity compared with white race/ethnicity, and inversely associated with higher educational attainment (college degree *v.* high school or lower: aOR = 0·56 for men and 0·48 for women) and double red cell donation and platelet donation.
Conclusions: Obesity is common among US blood donors, although of modestly lower prevalence than in the general population, and is associated with recognized demographic factors. Blood donors with higher BMI are specifically recruited for certain blood collection procedures. Blood centres can play a public health role in obesity surveillance and interventions.

Obesity has been described as epidemic in the USA, with significant adverse consequences for the incidence of diabetes and CVD, premature mortality and reduced quality of life[1–3]. According to National Center for Health Statistics data from the National Health and Nutrition Examination Survey (NHANES) 2007–2008, obesity prevalence by age was: 27·5 % in men and 34·0 % in women for ages 20–39 years; 34·3 % in men and 38·2 % in women for ages 40–59 years; and 37·1 % in men and 33·6 % in women for ages 60 years and above[4]. That study noted that the upward trend of obesity observed in the US population over the past 30 years may be levelling off in the decade since 1999–2000. The Centers for Disease Control and Prevention have also used self-reported height and weight data from the US Behavioral Risk

Factor Surveillance System (BRFSS) to estimate county-level prevalence of obesity. Counties with the highest prevalence of obesity were concentrated in West Virginia, the Appalachian counties of Tennessee and Kentucky, much of the Mississippi Delta, and the southern belt extending across Louisiana, Mississippi, middle Alabama, south Georgia and the coastal regions of the Carolinas[5]. However the authors noted limitations of both national surveillance mechanisms, including small sample size in sex and age strata for NHANES and potential response bias in the BRFSS.

Despite a moderate degree of selection bias due to volunteer bias and health criteria, blood donors provide a potential population for the ongoing surveillance of obesity and other health-related risk factors. Certainly such data

have been useful in surveillance for HIV and West Nile virus[6,7]. Data on large numbers of individuals are available from across the USA, and data are available continuously as opposed to episodic surveys. We are not aware of published data on BMI distributions among blood donors. Such information may be useful for public health surveillance, and also because body mass criteria are used to define eligibility for certain types of blood collection (e.g. double red cell donation) and prevention of syncopal reactions.

We therefore used data from a large, multicentre consortium of US blood centres to perform a descriptive analysis of BMI. Although the prevalence of obesity was modestly lower among blood donors compared with the general US population, demographic and geographic differences were observed that may be useful to ongoing public health surveillance.

Methods

Study population

The Retrovirus Epidemiology in Donors Study II (REDS-II) is a multicentre consortium of six blood centres located across the USA (see Table 1 and Appendix) which share data on all blood donations at their centres in a centralized research database. We included data on all successful allogeneic blood donations from donors at the six REDS-II centres from January 2007 to December 2008. All donors were un-remunerated volunteers. Autologous (those who donate for themselves) and therapeutic (those who are phlebotomized for medical indications) blood donations were excluded. Whole blood, double red cell and platelet apheresis donations were included. Donors who gave more than one donation during the study period contributed only one observation, namely data recorded at their first donation. Prospective blood donors weighing less than 110 lb (50 kg) are deferred from blood donation, as are donors under the age of 18 years who fail more stringent weight requirements and individuals with various medical or behavioural risks to safe blood donation, as reported previously[8–10]. Deferred donors were not included in the present study. Height and weight were self-reported by donors at the time of donation, and recorded by blood centre personnel on the blood donation record or a supplemental research form. Data collection was approved by the relevant institutional review boards at each blood centre and the coordinating centre.

Statistical analyses

BMI was calculated as weight (in kilograms) divided by the square of height (in metres). Density plots were constructed showing the proportion of the study population or subgroup with each integer value of BMI. Obesity was defined[4] as BMI $\geq 30 \cdot 0\,kg/m^2$, and overall and subgroup-specific prevalences of obesity were calculated. Crude obesity prevalences and empirical BMI

values are presented in Table 1 and Figs 1 and 2. Obesity prevalence was standardized by sex, age and race/ethnicity to the year 2000 US census population using the direct method[4]. Finally, adjusted odds ratios (aOR) for obesity and 95 % confidence intervals were calculated using multivariable logistic regression. All of the variables shown in Table 1, including education as a surrogate for socioeconomic status, were included in the model. All data analyses and multivariable models were conducted using the SAS statistical software package version 9·1 (SAS Institute Inc., Cary, NC, USA).

Results

We analysed data on donors who gave any type of allogeneic donation between 1 January 2007 and 31 December 2008. During this time 331 764 donors who were deferred from blood donation, including 2386 reports of low weight, were excluded from the analysis. A total of 38 386 (3·6 %) allogeneic donors were excluded because of missing height and/or weight data, leaving 1 042 817 for whom complete BMI data were available and included in the present study. The overall BMI distributions for men and women showed the following proportions of donors in each BMI category: (i) for men, 30 % were underweight/normal weight (BMI $\leq 24 \cdot 9\,kg/m^2$), 41 % were overweight (BMI $= 25 \cdot 0$–$29 \cdot 9\,kg/m^2$), 29 % were obese (BMI $\geq 30 \cdot 0\,kg/m^2$) and 9 % had grade 2 or 3 obesity (BMI $\geq 35 \cdot 0\,kg/m^2$); (ii) for women, 43 % were underweight/normal weight, 31 % were overweight, 26 % were obese and 11 % had grade 2 or 3 obesity. Men had higher mean BMI than women, although the distributions for both sexes were skewed to the right so that the proportion of women with very high BMI was similar to that of men.

The age-specific distributions of BMI for men and women (Figs 1(a) and 2(a)) show a clear shift in BMI with increasing age, with the <20 and 20–29 year age distributions (leftward peaks) clearly separated from the 40 year and older age groups (rightward peaks). The distributions of BMI differed by race ethnicity (Figs 1(b) and 2(b)), with Asians having the lowest BMI and blacks having more donors in the rightward tail of the distribution, particularly among women. Finally, unadjusted BMI distributions differed by educational attainment (data not shown). In men, those with a high school or lower education had a higher proportion of lower BMI while those with some college and college degrees had similar distributions. In women, the distributions of those with high school or lower education and those with college educations were similar, while women with some college had a higher proportion of obesity.

The crude prevalence of obesity was 25·1 % among all donors, 25·7 % in men and 24·4 % among women. We calculated the gender/age/race-standardized obesity prevalences for comparison with those reported by

Table 1 Prevalence of obesity (BMI ≥ 30·0 kg/m^2) by sex, donor demographics and other characteristics, and unadjusted/adjusted odds ratios and 95 % confidence intervals, among US blood donors, Retrovirus Epidemiology in Donors Study II (REDS-II), 2007–2008

Variable	Men						Women					
	n	% Obese	Unadjusted OR	95 % CI	Adjusted OR	95 % CI	n	% Obese	Unadjusted OR	95 % CI	Adjusted OR	95 % CI
Total donors	506 406	25·7					536 411	24·4				
Age (years)												
<20	104 039	13·0	0.55	0·54, 0·56	0·44	0·42, 0·45	114 096	11·3	0·47	0·46, 0·48	0·34	0·33, 0·35
20–29	77 787	21·4	1·00		1·00		94 857	21·3	1·00		1·00	
30–39	70 712	30·5	1·61	1·58, 1·65	1·83	1·79, 1·88	78 620	30·7	1·64	1·60, 1·67	1·81	1·77, 1·86
40–49	101 607	32·2	1·75	1·71, 1·78	1·94	1·89, 1·98	107 737	29·2	1·52	1·49, 1·55	1·67	1·63, 1·71
50–59	94 428	31·7	1·71	1·67, 1·75	1·92	1·88, 1·97	93 588	30·9	1·65	1·62, 1·69	1·81	1·77, 1·86
60–69	43 758	29·7	1·56	1·52, 1·60	1·73	1·69, 1·78	37 330	29·7	1·56	1·52, 1·60	1·66	1·61, 1·71
70+	14 075	21·4	1·00	0·96, 1·05	1·06	1·01, 1·11	10 183	23·5	1·14	1·08, 1·19	1·11	1·06, 1·17
Race/ethnicity												
White	432 971	25·8	1·00		1·00		454 588	23·8	1·00		1·00	
Black	27 005	32·6	1·39	1·36, 1·43	1·57	1·53, 1·62	35 059	39·0	2·05	2·01, 2·10	2·35	2·29, 2·41
Hispanic	19 760	26·6	1·04	1·01, 1·08	1·47	1·42, 1·52	22 269	24·4	1·03	1·00, 1·07	1·49	1·44, 1·54
Asian	14 518	11·4	0·37	0·35, 0·39	0·59	0·56, 0·63	11 989	9·1	0·32	0·30, 0·34	0·54	0·51, 0·58
Other	9362	24·1	0·91	0·87, 0·96	1·25	1·19, 1·32	10 194	23·8	1·00	0·96, 1·05	1·42	1·36, 1·50
Education												
≤High school	164 662	22·7	1·00		1·00		173 299	22·1	1·00		1·00	
Some college	143 208	31·8	1·59	1·56, 1·62	0·93	0·91, 0·95	178 771	30·1	1·52	1·50, 1·54	0·85	0·83, 0·86
≥College	192 023	23·8	1·06	1·04, 1·08	0·56	0·55, 0·57	178 962	21·2	0·95	0·93, 0·96	0·48	0·47, 0·49
Number of pregnancies												
Nulligravida							235 838	18·2	1·00		1·00	
One							56 185	30·3	1·95	1·91, 1·99	1·09	1·06, 1·11
Two							99 951	28·5	1·79	1·76, 1·82	0·90	0·88, 0·92
Three							67 321	29·3	1·86	1·82, 1·90	0·91	0·88, 0·93
Four							31 886	30·0	1·92	1·87, 1·98	0·93	0·90, 0·96
Five							13 204	30·8	2·00	1·93, 2·08	0·95	0·92, 1·00
Six or more							9146	32·1	2·12	2·03, 2·22	1·03	0·98, 1·08
Birthplace												
Not in USA	25 784	19·1	1·00		1·00		23 885	17·9	1·00		1·00	
USA	479 458	26·1	1·49	1·45, 1·54	1·38	1·33, 1·43	511 379	24·7	1·51	1·46, 1·56	1·45	1·40, 1·50
State of blood donation												
MA/CT/VT/ME*	164 258	24·6	1·00		1·00		169 637	22·3	1·00		1·00	
Pennsylvania	61 821	28·3	1·21	1·18, 1·23	1·08	1·06, 1·11	60 051	27·1	1·30	1·27, 1·33	1·14	1·11, 1·16
Georgia	124 168	27·2	1·14	1·13, 1·16	1·10	1·08, 1·12	144 113	26·4	1·25	1·23, 1·27	1·09	1·07, 1·11
Ohio	37 924	26·4	1·10	1·07, 1·13	1·07	1·04, 1·09	42 271	25·8	1·21	1·18, 1·24	1·13	1·10, 1·16
Wisconsin	64 593	26·6	1·11	1·09, 1·13	1·05	1·02, 1·07	68 854	25·5	1·20	1·17, 1·22	1·11	1·09, 1·14
California	53 642	21·1	0·82	0·80, 0·84	0·82	0·79, 0·84	51 485	20·3	0·89	0·87, 0·91	0·87	0·87, 0·91
Donor status												
Repeat donor	300 140	28·2	1·00		1·00		300 263	27·1	1·00		1·00	
First-time donor	203 950	22·0	0·72	0·71, 0·73	0·98	0·97, 1·00	233 661	21·0	0·72	0·71, 0·72	0·93	0·92, 0·94
Donation type												
Whole blood	443 059	25·0	1·00		1·00		519 498	24·0	1·00		1·00	
Double red cell	50 101	30·8	1·33	1·31, 1·36	1·39	1·36, 1·42	5659	48·4	2·97	2·82, 3·13	2·78	2·63, 2·94
Platelet apheresis	13 246	30·7	1·33	1·28, 1·38	1·17	1·13, 1·22	11 254	31·5	1·46	1·40, 1·52	1·29	1·24, 1·35
Donor's transfusion history												
Never transfused	465 112	25·4	1·00		1·00		497 056	23·9	1·00		1·00	
Ever transfused	14 464	31·0	1·32	1·27, 1·37	1·11	1·07, 1·15	22 147	32·2	1·51	1·47, 1·56	1·18	1·14, 1·21

Numbers in each subgroup may not sum to the totals due to missing data.
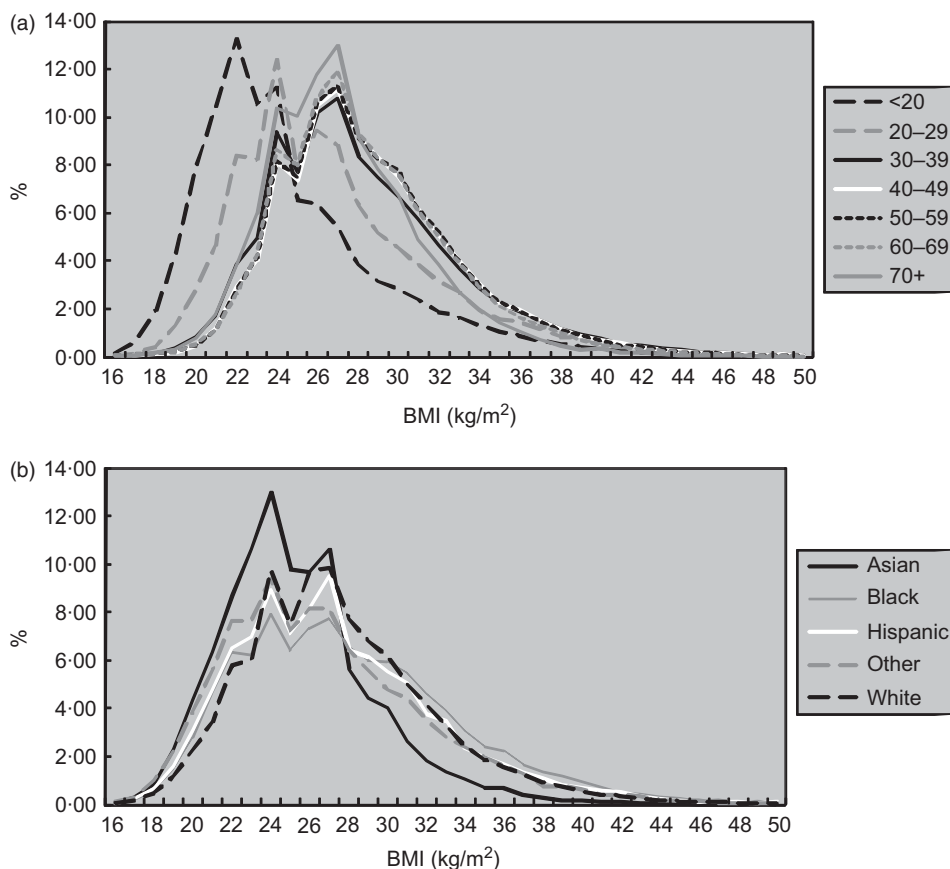*MA/CT/VT/ME, Massachusetts, Connecticut, Vermont and Maine.

Fig. 1 Distribution of BMI (kg/m^2) according to (a) age (years) and (b) race/ethnicity among male US blood donors (n 506 406), Retrovirus Epidemiology in Donors Study II (REDS-II), 2007–2008

NHANES. Among male blood donors, the standardized prevalence of obesity was 29·6 % (all ages), 26·9 % (age 20–39 years), 33·0 % (age 40–59 years) and 28·3 % (age 60 years plus), while among male NHANES participants it was 32·2 % (all ages), 27·5 % (age 20–39 years), 34·3 % (age 40–59 years) and 37·1 % (age 60 years plus). Among female donors, the standardized prevalence of obesity was 29·5 % (all ages), 27·3 % (age 20–39 years), 31·7 % (age 40–59 years) and 29·6 % (age 60 years plus), while among female NHANES participants it was 35·5 % (all ages), 34·0 % (age 20–39 years), 38·2 % (age 40–59 years) and 33·6 % (age 60 years plus). Thus male donors had obesity prevalence similar to that of NHANES at younger ages, while older male and all female donors had lower obesity prevalence than NHANES participants.

Table 1 shows the prevalence of obesity (BMI ≥ 30·0 kg/m^2) according to demographic and other characteristics of the donors, as well as aOR for the association between obesity and these characteristics. The prevalence of obesity rose with age, reaching a maximum in the 40–49 year age group for men and 50–59 year age group for women, and declining thereafter. Male and female donors of black and Hispanic race/ethnicity higher odds of obesity than those of white race/ethnicity, and black

women had more than twice the adjusted odds of obesity compared with white women. Asian donors had only half the adjusted odds of obesity compared with whites. The unadjusted prevalence of obesity was highest in donors with some college education, but controlling for age in the multivariable analysis showed aOR consistent with an inverse association of obesity with education. The association of obesity with increasing number of pregnancies among women showed a more complex relationship, with one pregnancy increasing the aOR by about 10 % and the next few pregnancies lowering the aOR, while for six or more pregnancies the aOR was no different from unity.

Donors born in the USA had increased odds of obesity compared with their foreign-born counterparts. There were also moderate regional differences in the prevalence of obesity. Donors at the four centres in Pennsylvania, Georgia, Ohio and Wisconsin had about 5–15 % higher adjusted odds of obesity than their counterparts in New England, while donors in California had more than 10 % lower adjusted odds compared with their New England counterparts.

Blood donation characteristics were also associated with the prevalence of obesity. Male and female repeat donors had a higher prevalence of obesity, although differences were minimal after adjustment for age and
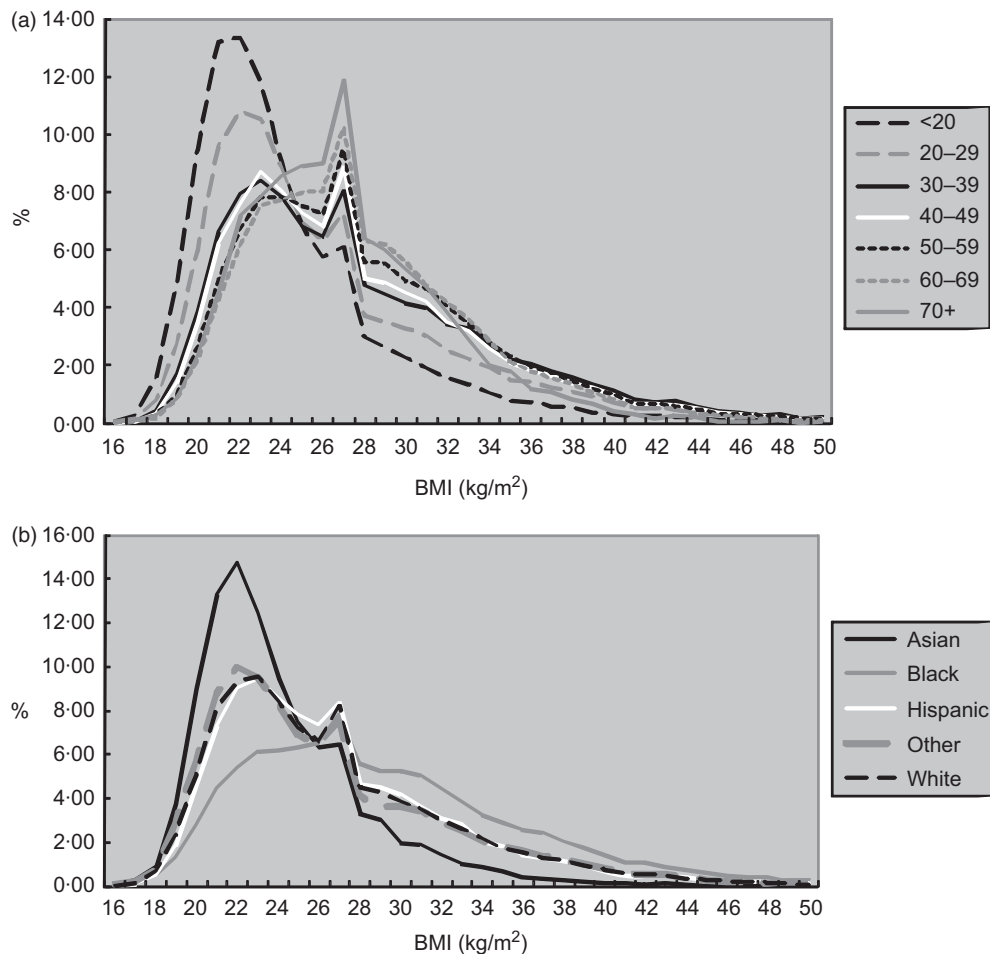
Fig. 2 Distribution of BMI (kg/m²) according to (a) age (years) and (b) race/ethnicity among female US blood donors (*n* 536 411), Retrovirus Epidemiology in Donors Study II (REDS-II), 2007–2008

other covariates (Table 1). Platelet apheresis donors had a slightly higher prevalence of obesity. Double red cell collections had a significantly higher prevalence of obesity, especially for women, consistent with minimum weight requirements for this type of donation. Finally, donors who have ever received a blood transfusion had a higher prevalence and odds of obesity compared with never transfused donors.

Discussion

These data, based on more than one million US blood donors, show a prevalence of obesity that is modestly lower than in the US general population, but still much higher than public health targets of 15 % obesity among adults[11]. We also found associations with age, race/ethnicity and education similar to those found in NHANES. Taken together, the data support the concept that the blood centre may be a useful venue for monitoring population trends in obesity and, potentially, introducing interventions towards the maintenance of healthy BMI.

Compared with age- and sex-specific NHANES data[4], blood donors had relative prevalences of obesity that were modestly lower in all age and sex subgroups, except for men aged 20–59 years who had obesity prevalence comparable to NHANES. These differences are likely due to selection bias operating on donors, including selection by the blood banks for healthy individuals and self-selection for donation by individuals with higher educational achievement, which is related to lower rates of obesity[12].

The distribution of BMI in both sexes showed a strong dependence on age. Most of this effect was likely due to biological factors, namely reduced metabolic demands in older persons coupled with a continued high caloric diet in the USA. However it is also conceivable that lower BMI in the youngest age groups represents a secular trend towards reduced BMI, as previously suggested[13,14]. Thus, recent public health educational efforts directed towards the young or changes in lifestyle may become durable as these groups age. Because of the large size and ongoing nature of the available data sets, prospectively gathered blood centre data could provide an excellent

opportunity for dissecting the effects of biological ageing and secular trends in the prevalence of obesity.

Projections of future trends in obesity have substantial implications for public health policy and expenditures related to CVD and other adverse outcomes of obesity. Olshansky *et al.* were the first to postulate a potential decline in US life expectancy during the 21st century due to obesity, despite gains made in the reduction of other cardiovascular risk factors[15]. For example, gains in life expectancy related to decreased prevalence of cigarette smoking, hypertension and dietary fat intake may be counterbalanced by an increasing prevalence of obesity[1,16]. Obesity may also be related to increased incidence of pancreatic and prostate cancer[17,18], decreased health-related quality of life[19], and increased mortality and decreased healthy survival in the elderly[3,20]. On a positive note, some authors have suggested that the epidemic of increasing obesity from 1970 to 2000 has begun to level off in the last decade, but additional data are needed to confirm this[4,21].

We also showed strong associations between obesity and race/ethnicity, country of birth and gravidity. Donors of black race/ethnicity, especially women, were more likely to have higher BMI and obesity prevalence, as observed in NHANES[4]. However those authors caution that differences in BMI between race/ethnic groups do not directly correlate with adiposity since muscle to fat ratios may differ by ancestry. Likewise, different race/ethnic groups may have difference risks for CVD or other adverse outcomes of obesity for any given BMI. As other authors have noted particularly among Hispanics, we observed that foreign-born donors had lower prevalence of obesity than US-born donors, consistent with the observation that immigrants have healthier diets than US-born donors[22]. Although women with a previous pregnancy were more likely to be obese than nulliparous women, we did not see a strong relationship between obesity and higher gravidity values, consistent with a previous report based upon NHANES data[23].

Whereas obesity was more prevalent in those with some college education than in those with high school or lower and college or higher education, the multivariate analysis showed an inverse relation with educational attainment. Higher socio-economic status is generally inversely associated with obesity in high-income countries but directly associated with obesity in lower-income countries[24]. However, data in the USA support a weakening of the inverse association between socio-economic status and obesity in recent decades, particularly among blacks[25]. Our data also showed regional differences in obesity prevalence within the USA that are similar to those reported elsewhere, and likely represent regional differences in diet and exercise[5].

We showed marked differences in obesity prevalence according to the type of blood donation made by the donor, in order of increasing obesity prevalence: whole blood donors; platelet apheresis donors; and double red cell donors. Compared with unadjusted OR, the aOR accounting for confounding by covariates showed some reduction for platelet donors but not for double red cell donors. This indicates that selection of donors for specific donation procedures according to body weight results in enrichment of obese donors. Whereas specific weight criteria are applied to double red cell donors in order to guarantee minimum blood volume, there are not overt weight criteria for platelet donation, although donors may be selected according to previous platelet yield, which in turn may be related to blood volume and body weight. On the other hand, the higher prevalence of obesity in repeat donors was attenuated in the multivariate analysis, suggesting confounding by age or other variables as well as selection for heavier (larger blood volume) repeat donors who can better maintain iron stores with repeated phlebotomy. We were surprised to find an increased prevalence of obesity among donors with a history of receiving a blood transfusion, with aOR = 1·11 (men) and 1·18 (women) after multivariable adjustment. Perhaps illnesses associated with obesity are also associated with an increased likelihood of blood transfusion, even among generally healthy blood donors. Finally, blood bankers should be aware of the high prevalence of obesity among female donors selected for automated collections, including the possibility that formulas based on height and weight may overestimate blood volume in obese donors. In order to prevent hypotensive reactions that are more frequent in donors with lower blood volume, such formulas may need to be adapted to account for adiposity *v.* lean body mass.

Strengths of the study include its very large population size, uniform collection of height and weight data as well as other covariates, and the ongoing nature of data collection in the blood centre setting. Limitations include the use of self-report instead of direct measurement of height and weight, because underestimation of weight and overestimation of height by respondents may have led to underestimation of BMI. A Swiss study found that self-reported height and weight underestimates BMI by 0·8 kg/m^2 in men and 1·0 kg/m^2 in women, and proposed an algorithm for transforming self-reported data[26]. A similar approach could be used to standardize US self-reported blood donor data to measured height and weight in a subsample of donors. Another limitation is the exclusion of individuals with very low body weight from blood donation and hence from participation in our data. Only 2326 (<0·3%) prospective donors were deferred for low body weight during our study period, although more persons may have self-deferred and not attempted to donate. Finally, a 'healthy donor' effect, namely selection bias of healthy individuals for blood donation, may operate in our data[12]. The exclusion for low weight would imply overestimation of BMI, whereas the 'healthy donor effect' would tend to exclude extremes of BMI. Nevertheless our data are comparable to albeit slightly lower than NHANES BMI data, suggesting that the extent of such biases is relatively modest.

Conclusions

We found a moderately high prevalence of obesity among otherwise healthy US blood donors, with demographic associations comparable to those seen in population-based studies. Because of the ongoing nature of data collection, the blood centre may be a useful venue for measuring period and cohort effects in BMI in obesity prevalence in the USA and other countries. As some blood centres move towards measurement of cholesterol and glycosylated Hb as a service to donors, the combination of these indices with BMI could lead to useful health education measures and even interventions to induce health-conscious blood donors to maintain healthier diet and lifestyles.

Acknowledgements

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Appendix