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High Levels of Serum Phosphorus Are Associated with Reduced Percentages of Body Fat: A Cross-sectional Study

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Abstract

An excessively high percentage of body fat can increase the risk of developing heart disease, diabetes, and other chronic diseases. This study examined two research questions: (1) What is the effect of serum phosphorus on the percentage of body fat? and (2) Does serum phosphorus have a different effect on the percentage of body fat in different parts of the body? This study investigated these questions using data from the National Health and Nutrition Examination Survey (NHANES). Nutritional and biochemical data were collected from the NHANES database from 2011 to 2018 on 15,653 participants, including 8,014 men and 7,639 women. Dual-energy X-ray absorptiometry (DXA) was used to assess the percentage of body fat of the study participants at the following body sites: the head, left arm, right arm, left leg, right leg, and trunk. Multivariate logistic regression was used to assess the odds ratios for excess fat percentages at several body sites in relation to serum phosphorus levels. The analyses found that high levels of serum phosphorus were associated with a smaller percentage of excess body fat in some areas of the body. Specifically, serum phosphorus levels exhibited a curvilinear association with increased body fat in the trunk, left arm, and right arm of females. As serum phosphorus levels increased in males, their percentage of body fat decreased in the trunk, left leg, right arm, and right leg.

Keywords

Adiposity; Body Composition; Fat Percentage; Gender; Obesity; Serum Phosphorus Levels; Sex Differences

1. Introduction

An excessively high percentage of body fat can increase the risk of developing heart disease [1], diabetes [2], and other chronic diseases [3]. Research has demonstrated that the percentage of excessively elevated body fat can give rise to a range of health issues, including obesity, diabetes, and cardiovascular diseases. Phosphorus is one of the essential elements that the human body cannot do without and it is widely distributed in various forms throughout the body's tissues. Some studies [4] suggest that phosphorus participates in the metabolic processing of fat, inhibiting the accumulation of fat, and reducing the risk of obesity. Does serum phosphorus influence the percentage of body fat? Does the impact of phosphorus on the percentage of body fat vary across different body sites? If such associations exist, what are the nature and extent of these effects? The objective of this study was to investigate the relationship between an excessive the percentage of body fat in different parts of the body and serum phosphorus, using population survey databases.

2. Methods and Materials

2.1 Study sample

This study utilized NHANES data from 2011-2018, the only cycles with DXA, body comp., and biochem exams. The NHANES protocol was IRB-approved, and this secondary analysis didn't need local ethics approval. Data on age, gender, race, diabetes status, income, poverty ratio, DXA fat percentages, and blood biochem params were extracted from the NHANES database. All the NHANES datasets and details about the NHANES can be found at https://www.cdc.gov/nchs/nhanes/about_NHANES.htm.

2.2 Diagnostic criteria and definition of groups

In line with technical reports [5] and clinical experience, men were defined as having excess body fat if their body fat exceeded 25% in different parts of the body, and women were defined as having excess body fat if method, which is based on bone density and body composition measurements. It measures bone density and body fat content using two different energy levels of X-rays. The advantages of this method include its high precision and accuracy, as it can differentiate between bone, fat, and lean tissue, thereby providing a detailed analysis of body composition. DXA is a commonly used method for assessing body composition because measurements can be completed in a relatively short time. A high level of quality control was maintained throughout the collection of the DXA data and the analysis of the scans, including a rigorous schedule of phantom scans.

2.3 Other measures

All blood samples are processed, stored, & sent to the Div. of Lab Sciences at NCEH/CDC for analysis. ICP-DRC-MS for Se, Pb, Cd, Hg, & Mn; Indirect ISE for K; ISE for Na & Ca; immunofluorescence for insulin, bilirubin, protein, triglycerides, creatinine, Fe, & P; glucose oxidase for glucose; UHPLC-MS/MS for vit D, 25OHD3, & 25OHD2; LC-MS/MS for folic acid.

2.4 Statistical analysis

The median (and interquartile range) are used to present all normally distributed continuous variables and skewed continuous variables. Frequencies (and %'s) are used to present categorical variables. Between-group comparisons of continuous variables were made using Student's t-test or the Mann-Whitney U-test, depending on the normality of the distribution. Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate.

Table 1. Characteristics of Male Participants Included in the Study from the NHANES (2011-2018)

			Male			
Variables	Total (n = 8014)	1 (n = 1913) 0.581≤P<1.195 umol/L	2 (n = 2094) 1.195≤P≤1.247 umol/L	3 (n = 1754) 1.195≤P<1.292 umol/L	4 (n = 2253) 1.292≤P≤2.163 umol/L	p
Hepf, n (%)						0.004
1	7202 (89.9)	1707 (89.2)	1907 (91.1)	1543 (88)	2045 (90.8)	
2	812 (10.1)	206 (10.8)	187 (8.9)	211 (12)	208 (9.2)	
Lapf, n (%)						< 0.001
1	3890 (48.5)	949 (49.6)	1003 (47.9)	686 (39.1)	1252 (55.6)	
2	4124 (51.5)	964 (50.4)	1091 (52.1)	1068 (60.9)	1001 (44.4)	
Llpf, n (%)						< 0.001
1	2745 (34.3)	685 (35.8)	752 (35.9)	426 (24.3)	882 (39.1)	
2	5269 (65.7)	1228 (64.2)	1342 (64.1)	1328 (75.7)	1371 (60.9)	

Table 1 Continued

Rapf, n (%)						< 0.001
1	4363 (54.4)	1072 (56)	1095 (52.3)	799 (45.6)	1397 (62)	
2	3651 (45.6)	841 (44)	999 (47.7)	955 (54.4)	856 (38)	
Rlpf, n (%)						< 0.001
1	2710 (33.8)	679 (35.5)	723 (34.5)	426 (24.3)	882 (39.1)	
2	5304 (66.2)	1234 (64.5)	1371 (65.5)	1328 (75.7)	1371 (60.9)	
Trpf, n (%)						< 0.001
1	3777 (47.1)	685 (35.8)	902 (43.1)	953 (54.3)	1237 (54.9)	
2	4237 (52.9)	1228 (64.2)	1192 (56.9)	801 (45.7)	1016 (45.1)	
Age	25.0 (14.0, 42.0)	38.0 (28.0, 49.0)	28.0 (16.0, 43.0)	11.0 (9.0, 24.0)	21.0 (15.0, 36.0)	< 0.001
Race, n (%)						< 0.001
Race1	1306 (16.3)	302 (15.8)	336 (16)	315 (18)	353 (15.7)	
Race2	767 (9.6)	180 (9.4)	183 (8.7)	184 (10.5)	220 (9.8)	
Race3	2650 (33.1)	692 (36.2)	684 (32.7)	511 (29.1)	763 (33.9)	
Race4	1779 (22.2)	381 (19.9)	417 (19.9)	452 (25.8)	529 (23.5)	
Race5	1078 (13.5)	287 (15)	325 (15.5)	196 (11.2)	270 (12)	
Race6	434 (5.4)	71 (3.7)	149 (7.1)	96 (5.5)	118 (5.2)	
RFIP	1.9 (1.0, 3.7)	2.0 (1.0, 4.0)	2.1 (1.1, 3.9)	1.6 (0.9, 3.3)	1.9 (1.0, 3.7)	< 0.001
Diabetes, n (%)						< 0.001
yes	348 (4.3)	129 (6.7)	104 (5)	33 (1.9)	82 (3.6)	
no	7666 (95.7)	1784 (93.3)	1990 (95)	1721 (98.1)	2171 (96.4)	
Ca	2.4 (2.3, 2.4)	2.4 (2.3, 2.4)	2.3 (2.3, 2.3)	2.4 (2.4, 2.4)	2.4 (2.4, 2.5)	< 0.001
Cr	73.4 (51.3, 86.6)	82.2 (73.4, 91.9)	72.2 (70.4, 91.9)	70.3 (51.5, 85.8)	76.9 (64.5, 88.4)	< 0.001
GLU	5.2 (4.8, 6.7)	5.2 (4.8, 5.8)	5.3 (4.9, 5.7)	5.1 (4.9, 5.6)	5.0 (4.6, 5.3)	< 0.001
Fe	17.4 (12.6, 26.8)	16.3 (12.7, 21.0)	15.3 (12.4, 20.6)	15.8 (10.6, 22.9)	15.2 (11.6, 19.7)	< 0.001
P	1.2 (1.2, 1.3)	1.1 (1.0, 1.1)	1.2 (1.2, 1.2)	1.3 (1.3, 1.3)	1.4 (1.4, 1.6)	< 0.001
Tb	12.0 (8.6, 20.5)	12.0 (8.6, 15.4)	12.6 (8.1, 16.1)	11.2 (7.6, 16.7)	10.3 (8.6, 13.7)	< 0.001
Tp	71.0 (66.0, 75.0)	72.0 (69.0, 75.0)	70.2 (68.1, 75.0)	71.5 (67.0, 75.1)	72.0 (70.0, 75.0)	< 0.001
Tr	1.1 (0.5, 1.8)	1.4 (0.9, 2.2)	1.0 (0.8, 1.5)	1.3 (1.0, 1.8)	1.2 (0.7, 2.0)	< 0.001
Folate	38.0 (26.1, 52.5)	32.7 (23.8, 45.4)	36.6 (24.8, 52.3)	46.4 (32.1, 62.7)	37.9 (26.8, 50.9)	< 0.001
VD	58.4 (44.4, 72.5)	56.4 (40.9, 70.9)	58.8 (44.9, 73.1)	60.5 (47.5, 74.5)	57.6 (44.0, 71.3)	< 0.001
25OHD2	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	0.031
25OHD3	56.3 (41.9, 70.4)	54.0 (38.7, 69.2)	56.7 (42.3, 70.8)	58.7 (45.5, 72.8)	55.6 (41.8, 69.0)	< 0.001
Lead	0.0 (0.0, 0.1)	0.0 (0.0, 0.1)	0.0 (0.0, 0.1)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	< 0.001
Cd	1.6 (1.0, 2.9)	2.0 (1.2, 4.0)	1.6 (1.0, 2.9)	1.1 (0.6, 2.0)	1.6 (1.0, 2.8)	< 0.001
Hg	2.8 (1.4, 6.2)	3.4 (1.7, 7.5)	2.7 (1.3, 6.2)	2.2 (1.0, 4.7)	2.9 (1.4, 6.2)	< 0.001
Se	2.4 (2.3, 2.5)	2.4 (2.4, 2.6)	2.4 (2.3, 2.6)	2.4 (2.2, 2.4)	2.4 (2.4, 2.5)	< 0.001

Table 1 Continued

Mn	170.7 (136.0, 214.8)	166.4 (131.1, 210.8)	171.8 (139.6, 213.7)	173.1 (136.9, 218.8)	172.2 (136.9, 216.1)	< 0.001
Insulin	58.4 (30.2, 105.2)	57.3 (32.8, 97.5)	57.3 (28.7, 109.1)	61.5 (26.0, 117.9)	58.3 (31.4, 101.1)	0.753
K	4.0 (3.9, 4.1)	3.9 (3.8, 4.2)	4.0 (3.9, 4.2)	4.0 (4.0, 4.0)	4.0 (3.8, 4.2)	< 0.001
Na	139.0 (138.0, 141.0)	139.0 (138.0, 140.0)	140.0 (138.0, 141.0)	139.2 (138.0, 140.6)	139.0 (138.0, 141.0)	< 0.001

Table 2. Characteristics of Female Participants Included in the Study from the NHANES (2011-2018)

Female						
Variables	Total (n = 7639)	1 (n = 1893)	2 (n = 1926)	3 (n = 1884)	4 (n = 1936)	p
		0.581≤P<1.227 umol/L	1.227≤P≤1.249 umol/L	1.249<P≤1.292 umol/L	1.292<P≤1.292 umol/L	
Hepf, n (%)						0.499
1	7638 (100.0)	1892 (99.9)	1926 (100)	1884 (100)	1936 (100)	
2	1 (0.0)	1 (0.1)	0 (0)	0 (0)	0 (0)	
Lapf, n (%)						< 0.001
1	956 (12.5)	90 (4.8)	258 (13.4)	374 (19.9)	234 (12.1)	
2	6683 (87.5)	1803 (95.2)	1668 (86.6)	1510 (80.1)	1702 (87.9)	
Llpf, n (%)						< 0.001
1	333 (4.4)	42 (2.2)	99 (5.1)	119 (6.3)	73 (3.8)	
2	7306 (95.6)	1851 (97.8)	1827 (94.9)	1765 (93.7)	1863 (96.2)	
Rapf, n (%)						< 0.001
1	1226 (16.0)	145 (7.7)	308 (16)	445 (23.6)	328 (16.9)	
2	6413 (84.0)	1748 (92.3)	1618 (84)	1439 (76.4)	1608 (83.1)	
Rlpf, n (%)						< 0.001
1	358 (4.7)	44 (2.3)	103 (5.3)	129 (6.8)	82 (4.2)	
2	7281 (95.3)	1849 (97.7)	1823 (94.7)	1755 (93.2)	1854 (95.8)	
Trpf, n (%)						< 0.001
1	2540 (33.3)	335 (17.7)	650 (33.7)	853 (45.3)	702 (36.3)	
2	5099 (66.7)	1558 (82.3)	1276 (66.3)	1031 (54.7)	1234 (63.7)	
Age	26.0 (14.0, 43.0)	37.0 (26.0, 46.0)	26.0 (14.0, 43.0)	13.0 (10.0, 31.2)	24.0 (16.0, 43.0)	< 0.001
Race, n (%)						< 0.001
Race1	1319 (17.3)	316 (16.7)	336 (17.4)	326 (17.3)	341 (17.6)	
Race2	818 (10.7)	201 (10.6)	185 (9.6)	201 (10.7)	231 (11.9)	
Race3	2469 (32.3)	660 (34.9)	616 (32)	568 (30.1)	625 (32.3)	
Race4	1648 (21.6)	431 (22.8)	372 (19.3)	454 (24.1)	391 (20.2)	
Race5	986 (12.9)	219 (11.6)	290 (15.1)	220 (11.7)	257 (13.3)	
Race6	399 (5.2)	66 (3.5)	127 (6.6)	115 (6.1)	91 (4.7)	
RFIP	1.8 (0.9, 3.7)	2.0 (0.9, 3.9)	1.9 (1.0, 3.7)	1.6 (0.8, 3.5)	1.8 (0.9, 3.6)	< 0.001

Table 2 Continued

Diabetes, n (%)						< 0.001
yes	347 (4.5)	114 (6)	77 (4)	62 (3.3)	94 (4.9)	
no	7292 (95.5)	1779 (94)	1849 (96)	1822 (96.7)	1842 (95.1)	
Ca	2.3 (2.3, 2.4)	2.3 (2.3, 2.4)	2.3 (2.3, 2.3)	2.4 (2.4, 2.4)	2.4 (2.3, 2.4)	< 0.001
Cr	58.3 (43.3, 69.8)	61.9 (54.8, 70.7)	55.8 (43.3, 65.8)	65.4 (53.2, 79.7)	61.0 (52.2, 69.0)	< 0.001
GLU	5.1 (4.7, 6.6)	5.0 (4.7, 5.6)	5.2 (4.8, 6.6)	5.0 (4.8, 5.4)	4.9 (4.6, 5.3)	< 0.001
Fe	15.0 (10.0, 24.9)	12.9 (9.0, 17.4)	12.9 (9.0, 17.4)	14.0 (9.0, 19.7)	12.7 (9.0, 17.2)	< 0.001
P	1.2 (1.2, 1.3)	1.1 (1.0, 1.2)	1.2 (1.2, 1.2)	1.3 (1.3, 1.3)	1.4 (1.4, 1.5)	< 0.001
Tb	10.3 (6.8, 17.1)	8.6 (6.8, 12.0)	10.4 (6.8, 17.1)	10.2 (6.8, 13.7)	8.6 (6.8, 12.0)	< 0.001
Tp	70.2 (65.0, 74.0)	71.0 (69.0, 74.0)	70.2 (65.0, 74.0)	71.8 (68.5, 75.0)	72.0 (69.0, 75.0)	< 0.001
Tr	1.0 (0.5, 1.6)	1.1 (0.7, 1.7)	1.1 (0.5, 1.3)	1.3 (0.9, 1.7)	1.0 (0.7, 1.7)	< 0.001
Folate	40.2 (27.8, 56.3)	36.8 (25.9, 51.0)	37.9 (25.7, 55.1)	47.0 (32.8, 64.6)	39.5 (28.6, 53.7)	< 0.001
VD	58.0 (42.6, 74.1)	56.1 (39.3, 74.5)	59.2 (44.7, 74.3)	58.5 (44.6, 73.5)	57.6 (42.2, 73.8)	0.002
25OHD2	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	1.4 (1.4, 1.4)	0.193
25OHD3	55.2 (39.4, 71.1)	52.8 (35.9, 71.2)	56.6 (41.0, 72.2)	56.4 (42.1, 70.6)	54.2 (39.0, 70.3)	< 0.001
Lead	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	< 0.001
Cd	1.9 (1.0, 3.5)	2.3 (1.4, 4.1)	2.0 (1.1, 3.6)	1.4 (0.9, 2.5)	2.0 (1.1, 3.6)	< 0.001
Hg	2.8 (1.4, 6.2)	3.4 (1.6, 7.2)	2.7 (1.2, 6.0)	2.3 (1.3, 4.9)	2.9 (1.5, 6.4)	< 0.001
Se	2.4 (2.3, 2.5)	2.4 (2.3, 2.5)	2.4 (2.2, 2.5)	2.4 (2.2, 2.4)	2.4 (2.3, 2.5)	< 0.001
Mn	190.6 (150.2, 244.2)	186.9 (145.8, 241.7)	195.7 (155.3, 245.7)	190.7 (152.7, 242.6)	189.2 (147.7, 245.9)	0.002
Insulin	59.5 (30.8, 106.1)	59.7 (34.3, 102.9)	59.7 (31.9, 106.6)	58.8 (25.7, 113.2)	59.5 (32.0, 102.6)	0.847
K	4.0 (3.8, 4.1)	3.8 (3.7, 4.1)	4.0 (3.8, 4.1)	4.0 (3.9, 4.0)	3.9 (3.8, 4.1)	< 0.001
Na	139.0 (138.0, 140.1)	139.0 (138.0, 140.0)	139.0 (138.0, 141.0)	139.0 (138.0, 140.3)	139.0 (138.0, 140.0)	< 0.001

Logistic regression was used to analyze the associations between serum phosphorus levels and the percentages of body fat at different body sites. Potential confounders were selected based on: (a) clinical relevance; (b) significance in univariate analyses; (c) association with the outcomes of interest; (d) changing the effect estimate by > 10%; or (e) having a $P < 0.1$. Two models were constructed: Model 1 was adjusted for age, race, the ratio of family income to the poverty line, and the presence of diabetes. Model 2 included additional adjustments for the following variables with P values < 0.1: blood concentrations of calcium, iron, potassium, sodium, lead, cadmium, mercury, manganese, total protein, total bilirubin, creatinine, vitamin D, vitamins D2/D3, folate, selenium, insulin, and glucose.

Table 3. Multivariate Relationship Between Serum Phosphorus Levels and Percentage of Body Fat at Different Body Sites

		Male				Female			
Model 1	Variable	n.total	n.event_%	adj.OR (95%CI)	adj.P	n.total	n.event_%	adj.OR (95%CI)	adj.P
Trpf	P	8014	4237 (52.9)	0.46 (0.35-0.6)	<0.001	7639	5099 (66.7)	0.24 (0.17-0.35)	<0.001
Hepf	P	8014	812 (10.1)	0.71 (0.46-1.08)	0.111	7639	1 (0)	0.04 (0-3789.32)	0.575
Lapf	P	8014	4124 (51.5)	0.63 (0.48-0.81)	<0.001	7639	6683 (87.5)	0.31 (0.19-0.5)	<0.001
Llpf	P	8014	5269 (65.7)	0.62 (0.47-0.81)	<0.001	7639	7306 (95.6)	0.45 (0.21-0.96)	0.04

Table 3 Continued

Rapf	P	8014	3651 (45.6)	0.61 (0.47-0.79)	<0.001	7639	6413 (84)	0.3 (0.19-0.46)	<0.001
Rlpf	P	8014	5304 (66.2)	0.58 (0.44-0.76)	<0.001	7639	7281 (95.3)	0.47 (0.23-0.97)	0.043
Model 2	Variable	n.total	n.event_%	adj.OR(95%CI)	adj.P	n.total	n.event_%	adj.OR(95%CI)	adj.P
Trpf	P	8014	4237 (52.9)	0.57 (0.42-0.75)	<0.001	7639	5099 (66.7)	0.03 (0-6969.2)	0.568
Hepf	P	8014	812 (10.1)	0.93 (0.6-1.45)	0.755	7639	1 (0)	0.26 (0.18-0.39)	<0.001
Lapf	P	8014	4124 (51.5)	0.77 (0.59-1.01)	0.057	7639	6683 (87.5)	0.36 (0.21-0.6)	<0.001
Llpf	P	8014	5269 (65.7)	0.75 (0.57-0.99)	0.041	7639	7306 (95.6)	0.55 (0.25-1.22)	0.142
Rapf	P	8014	3651 (45.6)	0.72 (0.55-0.95)	0.018	7639	6413 (84)	0.33 (0.21-0.53)	<0.001
Rlpf	P	8014	5304 (66.2)	0.7 (0.53-0.93)	0.012	7639	7281 (95.3)	0.56 (0.26-1.21)	0.141

Model 1: Adjusted for age, race, RFIP, and diabetes or not.
Model 2: Adjusted for age, race, RFIP, diabetes or not, and all the variables with a $P < 0.1$
Abbreviations: Ca: calcium, Cd: Cadmium, Cr: Creatinine, Fe: Iron, GLU: Glucose, Hepf: head fat percentage; K: Potassium, Lapf: left arm fat percentage; Llpf: left leg fat percentage; Mn: Manganese, Na: Natrium, P: Phosphorus, Rapf: right arm fat percentage; Race1: Mecican American, Race2: Other Hispanic, Race3: Non-Hispanic White, Race4: Non-Hispanic Black, Race5: Non-Hispanic Asian, Race6: Other Race RFIP: Ratio of family income to poverty, Rlpf: right leg fat percentage; Se: Selenium, Tb: Hg: Hydrargyrum, Total Bilirubin, Tp: Total Protein, Tr: Triglycerides, Trpf: trunk fat percentage.

Subgroup analyses were performed based on age, race, and diabetes status.

Table 4. Subgroup Analysis of the Association of Serum Phosphorus and Percent Body Fat by Age, Race, and Diabetic Status

			Male Trunk			Male Left Arm		
Subgroup	Variable	n.total	n.event_%	adj.OR (95%CI)	P	n.event_%	adj.OR (95%CI)	P
Age					0.136			0.182
age≤25	P	3912	1399 (35.8)	0.45 (0.3-0.68)	<0.001	2628 (67.2)	0.51 (0.35-0.76)	0.001
a25<age≤35	P	1277	727 (56.9)	0.84 (0.39-1.78)	0.643	849 (66.5)	0.67 (0.31-1.45)	0.315
35<age≤45	P	1155	828 (71.7)	0.88 (0.36-2.12)	0.768	766 (66.3)	1 (0.44-2.25)	0.991
45<age	P	1670	1283 (76.8)	1.09 (0.51-2.36)	0.82	1061 (63.5)	1.19 (0.62-2.29)	0.608
Diabetes					0.333			0.717
Yes	P	348	300 (86.2)	0.61 (0.08-4.45)	0.625	242 (69.5)	0.71 (0.17-3.03)	0.648
No	P	7666	3937 (51.4)	0.56 (0.42-0.75)	<0.001	5062 (66)	0.7 (0.53-0.94)	0.016
Race					0.089			0.018
Race1	P	1306	873 (66.8)	0.64 (0.29-1.42)	0.276	972 (74.4)	1.19 (0.53-2.67)	0.664
Race2	P	767	452 (58.9)	0.19 (0.07-0.52)	0.001	554 (72.2)	0.24 (0.09-0.64)	0.005
Race3	P	2650	1404 (53)	0.58 (0.36-0.94)	0.029	1871 (70.6)	0.86 (0.53-1.4)	0.544
Race4	P	1779	705 (39.6)	0.76 (0.42-1.37)	0.361	976 (54.9)	0.69 (0.4-1.17)	0.166
Race5	P	1078	597 (55.4)	0.7 (0.3-1.64)	0.418	651 (60.4)	0.73 (0.33-1.64)	0.447
Race6	P	434	206 (47.5)	0.3 (0.07-1.21)	0.09	280 (64.5)	0.46 (0.13-1.64)	0.23
				Male Right Arm			Male Left Leg	
Subgroup	Variable	n.total	n.event_%	adj.OR (95%CI)	P	n.event_%	adj.OR (95%CI)	P
Age					0.007			0.047
age≤25	P	3912	1754 (44.8)	0.42 (0.29-0.62)	<0.001	2618 (66.9)	0.52 (0.35-0.77)	0.001

Table 4 Continued

a25<age≤35	P	1277	519 (40.6)	0.86 (0.41-1.8)	0.691	842 (65.9)	0.64 (0.3-1.38)	0.257
35<age≤45	P	1155	535 (46.3)	1.18 (0.54-2.58)	0.671	755 (65.4)	1.48 (0.66-3.33)	0.342
45<age	P	1670	843 (50.5)	1.45 (0.76-2.74)	0.258	1054 (63.1)	1.28 (0.67-2.45)	0.458
Diabetes					0.569			0.898
Yes	P	348	231 (66.4)	0.88 (0.22-3.42)	0.849	242 (69.5)	0.48 (0.11-2.07)	0.327
No	P	7666	3420 (44.6)	0.73 (0.56-0.96)	0.026	5027 (65.6)	0.76 (0.57-1.01)	0.059
Race					0.047			0.057
Race1	P	1306	728 (55.7)	0.87 (0.43-1.77)	0.709	984 (75.3)	1.35 (0.59-3.07)	0.476
Race2	P	767	381 (49.7)	0.44 (0.18-1.08)	0.074	543 (70.8)	0.28 (0.11-0.76)	0.012
Race3	P	2650	1275 (48.1)	0.66 (0.42-1.03)	0.066	1842 (69.5)	0.9 (0.56-1.46)	0.672
Race4	P	1779	590 (33.2)	0.9 (0.51-1.58)	0.707	970 (54.5)	0.73 (0.43-1.23)	0.238
Race5	P	1078	485 (45)	1.17 (0.52-2.59)	0.707	649 (60.2)	0.76 (0.34-1.71)	0.511
Race6	P	434	192 (44.2)	0.2 (0.05-0.77)	0.019	281 (64.7)	0.42 (0.12-1.52)	0.186

			Female Trunk			Female Left Arm		
Subgroup	Variable	n.total	n.event_%	adj.OR (95%CI)	P	n.event_%	adj.OR (95%CI)	P
Age					0.536			0.427
age≤25	P	3603	1744 (48.4)	0.34 (0.2-0.57)	<0.001	2863 (79.5)	0.42 (0.22-0.81)	0.009
a25<age≤35	P	1147	846 (73.8)	0.14 (0.05-0.36)	<0.001	1047 (91.3)	0.14 (0.03-0.59)	0.007
35<age≤45	P	1197	986 (82.4)	0.37 (0.12-1.14)	0.084	1125 (94)	0.25 (0.05-1.38)	0.113
45<age	P	1692	1523 (90)	0.18 (0.06-0.55)	0.003	1648 (97.4)	0.24 (0.03-2.03)	0.19
Diabetes					0.545			0.914
Yes	P	347	335 (96.5)	0.09 (0-8.73)	0.305	345 (99.4)	7394.01 (0-Inf)	1
No	P	7292	4764 (65.3)	0.27 (0.18-0.39)	<0.001	6338 (86.9)	0.35 (0.21-0.6)	<0.001
Race					0.252			0.495
Race1	P	1319	999 (75.7)	0.43 (0.16-1.15)	0.094	1215 (92.1)	0.54 (0.12-2.49)	0.428
Race2	P	818	596 (72.9)	0.09 (0.03-0.34)	<0.001	747 (91.3)	0.21 (0.04-1.27)	0.09
Race3	P	2469	1576 (63.8)	0.17 (0.09-0.34)	<0.001	2165 (87.7)	0.29 (0.12-0.72)	0.008
Race4	P	1648	1052 (63.8)	0.37 (0.15-0.89)	0.026	1322 (80.2)	0.3 (0.11-0.83)	0.021
Race5	P	986	635 (64.4)	0.4 (0.15-1.12)	0.081	895 (90.8)	0.72 (0.14-3.79)	0.701
Race6	P	399	241 (60.4)	0.32 (0.05-1.91)	0.212	339 (85)	0.16 (0.01-1.8)	0.139

			Female Right Arm		
Subgroup	Variable	n.total	n.event_%	adj.OR(95%CI)	P
Age					0.129
age≤25	P	3603	2674 (74.2)	0.5 (0.29-0.86)	0.013
a25<age≤35	P	1147	1021 (89)	0.13 (0.04-0.46)	0.001
35<age≤45	P	1197	1089 (91)	0.49 (0.12-1.99)	0.318
45<age	P	1692	1629 (96.3)	0.09 (0.02-0.46)	0.004

Table 4 Continued

Diabetes					0.865
Yes	P	347	341 (98.3)	0.1 (0-45.44)	0.463
No	P	7292	6072 (83.3)	0.24 (0.15-0.36)	<0.001
Race					0.059
Race1	P	1319	1171 (88.8)	0.3 (0.09-0.94)	0.038
Race2	P	818	712 (87)	0.13 (0.03-0.55)	0.005
Race3	P	2469	2081 (84.3)	0.26 (0.12-0.56)	0.001
Race4	P	1648	1261 (76.5)	0.08 (0.04-0.2)	<0.001
Race5	P	986	865 (87.7)	0.37 (0.1-1.42)	0.149
Race6	P	399	323 (81)	0.31 (0.04-2.15)	0.234

3. Results

3.1 Characteristics of participants

The analysis included 15,653 participants between the ages of 8 and 59 years, of which 8,014 were males and 7,639 were females. Tables 1 and 2 show the baseline characteristics of males and females, respectively, stratified into four groups by their serum phosphorus levels.

Table 1 shows that the prevalence of excessive body fat among males in the study was 52.9% in the trunk, 10.1% in the head, 51.5% in the left arm, 65.7% in the left leg, 45.6% in the right arm, and 66.2% in the right leg. Table 2 shows that the prevalence of excessive body fat among females in the study was 66.7% in the trunk, 0.0% in the head, 87.5% in the left arm, 95.5% in the left leg, 84% in the right arm, and 95.3% in the right leg. The groups differed significantly in terms of age, race, income level, and diabetes ($P < 0.05$). There were 695 individuals in the study with diabetes (4.46%).

3.2 Association of serum phosphorus levels with excess fat at different body sites

Table 4 shows the results of the subgroup analyses based on age, race, and diabetes status. When the serum phosphorus level increased by 1 micromole in men, none of these three variables was significantly associated with the percentage of trunk fat ($P > 0.05$). However, the analyses revealed that people of other races were less likely to have excess fat in the right arm (OR = 0.2, P = 0.019). Further analyses revealed that people younger than 25 years were also less likely to have excess fat in their right arm (OR = 0.42, P < 0. 001), as well as their left leg (OR = 0.52, P < 0.001). Diabetes had a significant association with lower excess adiposity in the right arm.

3.3 Analysis of the threshold influence of serum phosphorus on excess fat at different body sites

A smoothing function revealed a non-linear dose-response between serum phosphorus and excess fat percentage. In males, a significant non-linear relationship was found in the right arm ($P < 0.05$) with a break point at 1.247 mmol/l. No such relationship was seen in the trunk or legs. In contrast, women showed significant non-linear relationships in the trunk and arms (all Ps < 0.05) with a break point at 1.249 μmol/l.

4. Discussion

The results of this study showed that the serum phosphorus level of men was negatively associated with excess fat in the trunk, right arms, left legs, and right legs. However, the serum phosphorus level of women was positively associated with excess fat in the trunk, left arms, and right legs, when the serum phosphorus level was less than 1.249 mmol/L, but negatively associated with excess fat at the same body sites when the serum phosphorus level was greater than 1.249 mmol/L. There was no significant association with excess fat at other body sites. Furthermore, after adjusting for residual confounders, the associations remained significant and consistent across the age, race, and diabetes subgroups. This phosphorus level is within the recommended serum phosphorus levels (1.1-1.5 mmol/L) [6].

Phosphorus is a crucial element in the body, found in tissues as phospholipids and phosphates, essential for genetic metabolism, growth, energy, and acid-base balance [7]. Phosphorus is also involved in fat metabolism, reducing fat storage, and the risk of obesity by converting proteins and fats in food into energy for the body [4]. Phosphorus in the body forms phospholipids with fat, regulating inflammatory mediators and key in fat metabolism and waste removal for health. Bone phosphates aid in insulin glucose uptake and decrease insulin secretion [8], while insulin promotes glycogen synthesis and fat formation while inhibiting fat breakdown [9]. Phosphorus intake can decrease body fat linked to insulin, with studies showing lower phosphorus correlates with higher BMI. Phosphorus supplements over 3 months reduce weight, BMI, and waist size, and increase post-meal fullness in obese individuals [10, 11]. Animal models [12, 13] have shown that a phosphorus-rich diet can inhibit white adipose tissue activity by increasing fat breakdown and reducing the expression of fat-forming genes. In summary, a growing body of research suggests that high phosphorus levels are negatively related to fat deposition in the body. One study suggests [14] that under high phosphorus conditions, the body can prevent fat deposition by controlling food intake, reducing calorie expenditure, and reducing physical activity, thereby reducing the risk of obesity, which is associated with increased hepatic adenosine triphosphate (ATP) production [15, 16], increased insulin secretion [17], and reduced oxygen affinity of hemoglobin [18, 19].

Ağbaht and Pişkinpaşa [20], who conducted a retrospective analysis using data collected from local clinics, found that phosphorus supplementation in obese patients increased their resting metabolic rate. It is important to note that insufficient phosphorus levels are a concern in the assessment of obesity, especially morbid obesity. Phosphorus is found in the blood in the form of phosphates (H2PO4-) and (HPO4-), but its concentration is typically measured in terms of phosphorus, with a normal range of 3.4–4.5 mg/Dl [6]. The American Institute of Medicine's Dietary Reference Intake (DRI) Scientific Assessment Subcommittee recommended a daily phosphorus intake of 700 mg (22.6 mmol) per day, with a daily upper limit (UL) of nutrient intake of 4,000 mg per day [21]. When dietary phosphorus intake is much higher than the UL, metabolic diseases may occur, such as hypocalcaemia, osteoporosis, nephropathy, and obesity [22-24].

A key advantage of this study is the utilization of DXA to quantify the percentage of body fat at several body sites. Moreover, the results are based on six outcomes, each representing whether the fat percentage within a specific body site (head, trunk, or extremities) exceeded the established standard value, and the study considers the impact of serum phosphorus on the fat percentage at these different body sites, taking into account the differences in fat percentages between males and females. It also discusses the effects of phosphorus on fat rates in males and females.

Some limitations of this study should be noted. First, the study used cross-sectional data and causal inferences cannot be drawn based on cross-sectional designs. Second, the analysis of serum phosphorus levels did not consider the potential effects of phosphorus supplementation. Third, the NHANES data used in this study were only from the period between 2011 and 2018. However, given the reputation of the NHANES for accuracy and objectivity, the conclusions drawn from these results should be robust and unbiased. Nevertheless, prospective studies are needed to validate the value of the study's findings in contemporary populations.

In conclusion, the findings indicate that elevated levels of serum phosphorus are associated with a reduction in the risk of exceeding the standard fat percentage in the trunk, left leg, right arm, and right leg of men, and a similar reduction can also be observed in the trunk, left arm, and right arm of women. The results on serum phosphorus control of excess fat can be used as a reference for patients with high levels of fat in different parts of the body.

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