British Journal of Nutrition

cambridge.org/bjn

Research Article

Cite this article: Zhang J, Fang W, Chen S, and Wang L (2024) Dietary total antioxidant capacity is closely associated with skeletal muscle mass: a cross-sectional study. *British Journal of Nutrition* **132**: 1674–1683.
doi: 10.1017/S0007114524002575

Received: 8 December 2023
Revised: 18 August 2024
Accepted: 10 October 2024
First published online: 12 November 2024

Keywords:
Total antioxidant capacity; Skeletal muscle mass; Ageing; NHANES

Abbreviations:
NHANES, National Health and Nutrition Screening Survey; TAC, total antioxidant capacity

Corresponding authors:
Lu Wang;
Email: lawanglu@163.com;
Shuiping Chen; Email: shpchen@hotmail.com

†These authors contributed equally to this work.

Dietary total antioxidant capacity is closely associated with skeletal muscle mass: a cross-sectional study

Jie Zhang[1,†], Wendong Fang[2,†], Shuiping Chen[2] and Lu Wang[1]

[1]Clinical Laboratory Department, Lu'an People's Hospital, Lu'an 237000, Anhui Province, People's Republic of China and [2]The Fifth Medical Center of PLA General Hospital, The Fifth School of Clinical Medicine, Anhui Medical University, Hefei 230032, Anhui Province, People's Republic of China

Abstract

Skeletal muscle is of great importance for human activity and quality of life, as its loss contributes greatly to immobilisation, especially for aged individuals. An increased dietary intake of antioxidant vitamins may be beneficial for muscle loss because of ageing. However, the quantitative relationship between total antioxidant capacity (TAC) of antioxidant vitamins and muscle mass is undetermined. Totally, 4009 participants from the National Health and Nutrition Examination Survey (NHANES) were included. Multivariate linear regression analysis was performed with demographic, lifestyle and dietary intake adjustment factors. The dose saturation effect was also determined by a saturation effect analysis. Subgroup analysis was performed for age and sex. In the fully adjusted model, per unit increase of dietary TAC was associated with an increase of 0·018 g/kg appendicular lean mass (95 % CI 0·007, 0·029), 0·014 g/kg trunk lean mass (95 % CI 0·004, 0·024) and 0·035 g/kg total lean mass (95 % CI 0·014, 0·055). TAC was associated with a decrease of 0·004 kg/kg total percent fat (95 % CI −0·006, −0·002), 0·005 kg/kg trunk percent fat (95 % CI −0·007, −0·002) and 0·003 kg/m^2 BMI (95 % CI −0·006, −0·001) at the same time. Subgroup analysis indicated that women and adults < 50 years may experience the most significant association between TAC and skeletal muscle mass. We revealed a positive correlation between TAC and lean body mass and a negative association between TAC and body fat and BMI. Saturation values were found among people aged 40–59 years. Age and sex mediate these associations.

Skeletal muscle, one of the most dynamic and plastic tissues in the human body, accounts for approximately 40 % of the total body weight in humans and is fundamental to movement, energy homoeostasis and overall quality of life[1–3]. However, skeletal muscle mass begins to decline in middle-aged and older adults, and adults between the ages of 40 and 80 years have already lost approximately 20 % of their skeletal muscle mass during their lifetime[4,5]. Muscle mass decline makes middle-aged and older adults vulnerable to bone fractures and chronic metabolic diseases, such as type 2 diabetes and obesity, leading to a significant increase in healthcare costs[6,7]. Apart from that, muscle loss has even been reported as an independent risk factor for high mortality in older individuals[8,9]. However, effective and strategic muscle-sparing intervention methods for older adults have not yet been revealed.

In recent years, researchers have found that the level of oxidative stress in skeletal muscle increases with age, and the imbalance between increased reactive oxygen species production and overall antioxidant defence is one of the leading causes of muscle damage[10,11]. At the same time, a series of studies have shown that dietary intake of antioxidant vitamins is associated with lower reactive oxygen species and better-preserved muscle mass[12–14]. Additionally, exogenous supplementation of appropriate amounts of vitamins can protect against muscle loss during ageing[15,16]. Total antioxidant capacity (TAC) is a term that reflects the antioxidant potential of dietary sources, which are mainly a combination of various vitamins[17–21]. Researchers believe that TAC participates in the progression of several diseases, such as hypertension and cancer[22,23]. However, the relationship between TAC and muscle loss has been scarcely studied. In patients with liver cirrhosis, researchers found that TAC was positively correlated with grip strength and arm muscle area[24]. Other animal experiments have confirmed that antioxidant supplementation can improve skeletal muscle quality[25,26]. Given the higher risk of muscle mass loss in the middle-aged population than in the younger population, studies targeting TAC and muscle loss in this population are urgent and valuable.

Based on the National Health and Nutrition Screening Survey (NHANES) database, the purpose of this study was to investigate the association between dietary TAC of antioxidant vitamins and skeletal muscle mass in middle-aged individuals in the USA after adjusting for potential risk factors.

https://doi.org/10.1017/S0007114524002575 Published online by Cambridge University Press

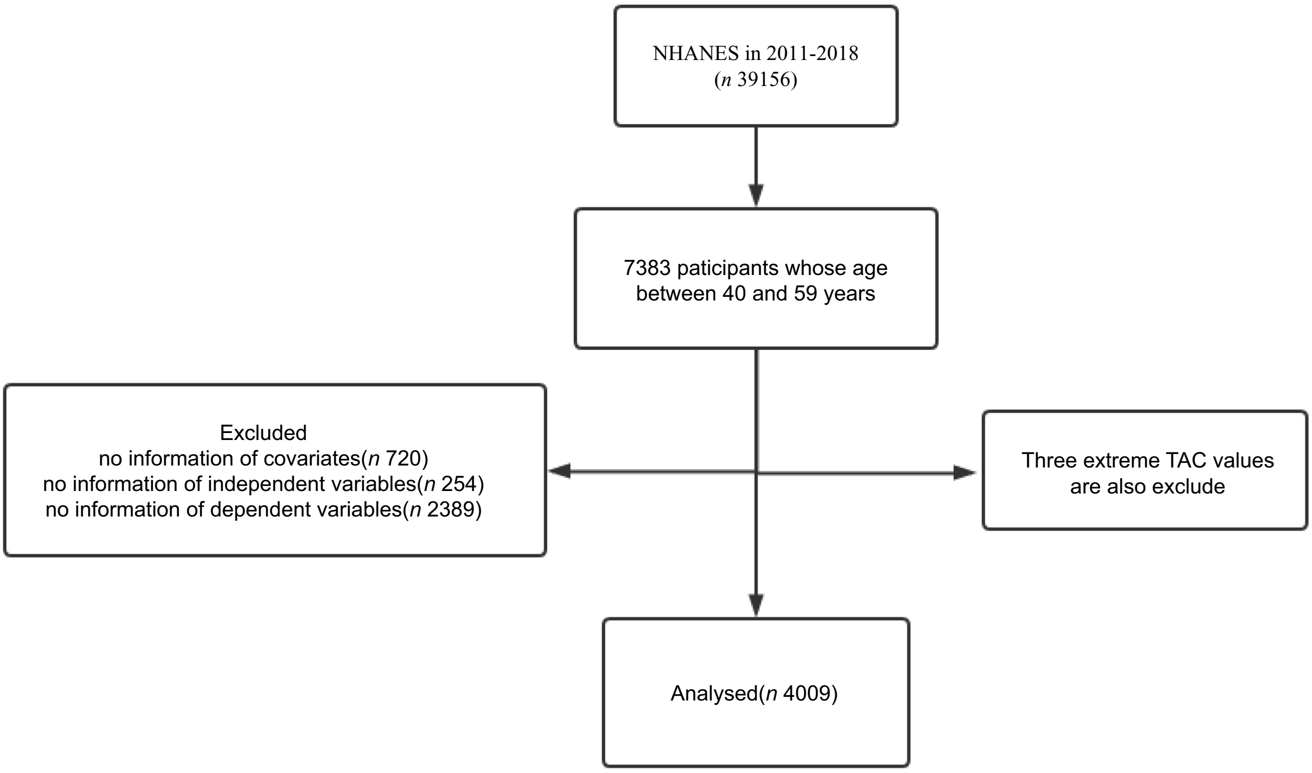

Fig. 1. Flow chart for participant inclusion and exclusion. NHANES, National Health and Nutrition Screening Survey; TAC, total antioxidant capacity.

Methods

Study population

NHANES is a representative US population survey that uses complex multilevel probability sampling to provide information on the nutritional status and health status of the general US population. The NHANES research programmes were approved by the NCHS Research Ethics Review Committee and received written informed consent from the participants.

This study uses the US NHANES database for the rolling period 2011–2018 (*n* 39 156). After excluding patients with missing information on demographics, diet, examination and questionnaires, a total of 4009 subjects were included in the analysis. Figure 1 shows an example of a selection flow chart.

Estimation of total antioxidant capacity from diet

On the first day of the interview, participants were asked to report in detail all food and beverages consumed in the past 24 h. Subsequently, after 3–7 d, the researcher collected dietary intake for the past 24 h again by telephone. The researchers then converted this information into nutrient intakes based on the USDA's Food and Nutritional Database (FNDDS). The antioxidant vitamins recorded in the NHANES dietary interview consisted of vitamin A, vitamin C, vitamin E, α-carotene, β-carotene, β-cryptoxanthin, lycopene and lutein-zeaxanthin. According to Floegel et al.[27], the individual antioxidant capacity of participants was determined by multiplying the individual amount of antioxidant compounds (antioxidant vitamins) by their antioxidant capacities:

$$\text{Theoretical TAC} = \Sigma\left(\text{antioxidant content}\,\frac{\text{mg}}{100\ \text{g}} \times \text{antioxidant capacity}\,\frac{\text{mg VCE}}{100\ \text{g}}\right)$$

Antioxidant capacity was measured in the laboratory by chemical combustion, and the antioxidant capacity of vitamin C was used as a benchmark to assess the antioxidant capacity of other vitamins. In our study, we averaged the antioxidant nutrient intakes from the two surveys. TAC was divided into Q1 (0·236 to 22·188 mg VCE/100 g), Q2 (22·188 to 53·255 mg VCE/100 g), Q3 (53·255 to 112·933 mg VCE/100 g) and Q4 (112·933 to 779·247 mg VCE/100 g) according to the survey-weighted quartile.

Covariates

The demographic factors included age, sex (Men and Women), race (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black and Other Race) and socio-economic status (Low, PIR $< 1{\cdot}3$; Middle, $1{\cdot}3 \leq \text{PIR} \leq 3{\cdot}5$; High, PIR $> 3{\cdot}5$). Lifestyle factors consisted of alcohol consumption (yes and no), smoking status (never, former and now), physical activity (none, moderate and heavy) and sedentary activity (online Supplementary Table S1). Other factors reported in the study that may influence body mass were obtained from the interview diet data and included protein, dietary fibre, Ca and phosphorus intake[28].

Dependent variables

There are six dependent variables in this study, including appendicular relative lean mass (relative to body weight, g/kg),

Table 1. Baseline characteristics of the participants grouped by TAC quartiles

	All (*n* 4009)		Q1		Q2		Q3		Q4		*P*
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Age (year)	49·69	0·17	48·91	0·29	49·83	0·21	49·81	0·32	50·22	0·32	0·025
	%	SE	%	SE	%	SE	%	SE	%	SE	
Sex											0·044
Men	50·18	1·21	46·63	2·35	52·84	2·23	47·08	2·55	54·58	2·54	
Women	49·81	1·21	53·37	2·35	47·16	2·23	52·92	2·55	45·42	2·54	
Race											0·027
Mexican American	8·39	1·01	6·76	1·03	9·1373	1·39	7·93	1·16	9·87	1·67	
Other Hispanic	5·86	0·78	4·25	0·87	5·92	0·93	6·08	1·04	7·26	1·08	
Non-Hispanic White	66·19	2·23	70·50	3·10	66·23	2·66	66·87	2·76	60·84	2·98	
Non-Hispanic Black	10·18	1·02	10·25	1·52	10·01	1·30	9·3991	1·13	11·12	1·14	
Other Race	9·38	0·77	8·25	1·25	8·70	1·10	9·72	1·09	10·92	1·48	
Socio-economic status											< 0·001
Low	18·58	1·46	24·07	2·68	19·27	1·47	14·48	1·68	16·41	1·86	
Middle	31·60	1·49	35·94	2·53	33·36	2·80	30·99	2·30	25·85	2·17	
High	49·82	2·04	39·99	3·07	47·37	3·07	54·53	2·68	57·74	2·81	
BMI (kg/m^2)											0·054
Thin	0·76	0·19	0·83	0·34	0·89	0·42	0·95	0·53	0·3663	0·19	
Normal	24·81	1·03	21·18	1·73	21·23	1·65	27·99	2·27	28·90	2·04	
Overweight	36·59	1·24	37·77	2·14	37·67	2·03	34·76	2·67	36·18	2·20	
Obese	37·84	1·32	40·22	1·93	40·21	2·09	36·29	2·45	34·55	2·43	
Alcohol											0·613
No	22·63	1·10	23·90	2·19	20·33	1·68	22·62	2·23	23·65	2·30	
Yes	77·37	1·10	76·10	2·19	79·67	1·68	77·38	2·23	76·35	2·30	
Smoking											< 0·001
Never	52·56	1·43	45·96	2·52	50·25	2·21	57·41	2·50	56·76	2·67	
Former	24·65	1·02	21·19	2·06	24·93	2·20	24·64	2·04	28·05	2·54	
Now	22·79	1·16	32·85	2·25	24·82	2·06	17·95	1·91	15·19	1·89	
Physical activity											< 0·001
No	44·25	1·3	53·98	2·63	44·75	2·12	41·93	2·74	35·89	2·55	
Moderate	31·45	1·39	28·89	2·58	34·04	2·29	33·21	2·62	29·55	2·33	
Heavy	24·32	1·35	17·13	2·07	21·21	2·01	24·86	2·56	34·56	2·65	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Sedentary activity (min/d)	423·16	13·78	457·07	44·39	405·30	13·81	433·80	24·24	393·95	10·93	0·288
Appendicular relative lean mass (g/kg)	274·69	1·10	268·91	1·88	273·86	2·03	275·11	2·44	281·22	1·97	< 0·001
Trunk relative lean mass (g/kg)	321·92	0·97	318·37	1·83	322·33	1·34	322·17	1·91	324·99	1·83	0·036
Total relative lean mass (g/kg)	635·72	1·95	625·74	3·57	635·19	3·14	636·75	4·23	645·74	3·59	0·001
Total percent fat	33·88	0·20	34·91	0·36	33·95	0·32	33·74	0·44	32·86	0·37	< 0·001
Trunk percent fat	33·45	0·21	34·47	0·32	33·79	0·32	33·02	0·44	32·46	0·39	< 0·001
Protein (g/d)	84·90	0·91	68·47	1·31	84·33	1·72	92·21	1·77	95·10	2·00	< 0·001

(*Continued*)

https://doi.org/10.1017/S0007114524002575 Published online by Cambridge University Press

Table 1. (*Continued*)

	All (*n* 4009)		Q1		Q2		Q3		Q4		*P*
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Dietary fibre(g/d)	17·63	0·30	11·25	0·31	16·03	0·36	20·17	0·61	23·30	0·54	< 0·001
Ca (mg/d)	978·90	15·96	768·33	23·79	953·71	23·92	1051·35	31·77	1150·83	34·66	< 0·001
Phosphorus (mg/d)	1435·37	17·07	1159·40	25·29	1409·23	26·57	1558·90	33·21	1622·60	32·79	< 0·001

TAC, total antioxidant capacity.
Data are presented by % (SE) for categorical variables or mean (SE) for continuous variables.

trunk relative lean mass (relative to body weight, g/kg), total relative lean mass (relative to body weight, g/kg), total percent fat (percent of body weight, %), trunk percent fat (percent of body weight, %) and BMI (kg/m^2).

Through dual-energy X-ray absorptiometry, the lean body mass (excluding bone mineral content) and fat content of participants' left and right legs, left and right arms, and trunk were measured separately. The appendicular relative lean mass is calculated by summing the lean body mass (excluding bone mineral content) of the left and right legs and arms. In addition, to account for the effects of body weight on these results, all dependent variables are relative to body weight (all lean body mass is per kilogram of body weight g; all fat is per kilogram of body weight kg).

Statistical analysis

The statistical analysis was conducted by using the statistical computing and graphics software R (version 4.2.1) and EmpowerStats (version 5.0). Continuous variables were compared for between-group differences using *t* tests or one-way ANOVA, expressed as mean (standard error) (SE), and categorical variables were compared for between-group differences using non-parametric tests, as well as expressed as frequencies (percentages). After satisfying the linear regression assumptions, we determined the β and 95 % CI by analysing a multivariate linear regression between the TAC and all outcomes. The multivariate linear regression was built using three models: Model 1: not adjusted; Model 2: adjusted for sex, age, race and socio-economic status; Model 3: adjusted for all covariates. In addition, considering the non-normality of the TAC distribution, we again performed multivariate linear regression analyses by log-transforming the TAC. Smoothed curve fits were carried out concurrently with the variable adjustments. We used a threshold effects analysis model to examine the relationship and saturation effect between TAC and body mass. Finally, subgroup analysis was used to determine the population who experienced the most benefit. We used dietary day one sample weight to analyse all the results, and $P < 0{\cdot}05$ was considered statistically significant.

Results

Descriptions of participants

The characteristics of weighted demographics, dietary data and lifestyle of the participants are shown in Table 1. A total of 4009 participants were included in this study. Of these participants, the average age was 49·69, and 50·18 % were man. Among different groups of TAC (quartiles, Q1–Q4), age, sex, race, socio-economic status, smoking, physical activity, appendicular relative lean mass, trunk relative lean mass, total relative lean mass, total percent fat, trunk percent fat, protein, dietary fibre, Ca and phosphorus were all significantly different ($P < 0{\cdot}05$). The relationships between the dependent variables and the covariates can also be seen in online Supplementary Table S2.

Relationship between total antioxidant capacity and skeletal muscle mass

There was a significant positive association between dietary TAC and lean body mass in three weighted univariate and multivariate linear regression models (Table 2). In the fully adjusted model, each 1-unit increase in dietary TAC was associated with an increase of 0·018 g/kg appendicular lean mass (95 % CI 0·007, 0·029), 0·014 g/kg trunk lean mass (95 % CI 0·004, 0·024) and 0·035 g/kg total lean mass (95 % CI 0·014, 0·055).

Dietary TAC also showed a significant negative association with total percent fat, trunk percent fat and BMI (Table 3). Assuming linearity, each 1-unit increase in dietary TAC was associated with −0·004 kg/kg total percent fat (95 % CI −0·006, −0·002), −0·005 kg/kg trunk percent fat (95 % CI −0·007, −0·002) and −0·003 kg/m^2 BMI (95 % CI −0·006, −0·001). Furthermore, after log-transforming TAC, a significant association between TAC and skeletal muscle mass was still found (online Supplementary Table S3).

Dose–response relationships and their saturation effect

Figure 2 shows the dose–response relationship between dietary intake and TAC for all outcomes. Combining the smoothing curve and TAC quartile, a saturation effect was found between TAC and all outcomes. Then, a saturation effect analysis explored these turning points, and the saturation effect value was 67·433 mg VCE/100 g in the appendicular relative lean mass, 64·072 mg VCE/100 g in the trunk relative lean mass, 64·809 mg VCE/100 g in the total relative lean mass, 67·433 mg VCE/100 g in the total percent fat, 65·955 mg VCE/100 g in the trunk percent fat and 71·167 mg VCE/100 g in BMI (Table 4).

Subgroup analysis of the association between dietary total antioxidant capacity and skeletal muscle mass

Our study population contained participants aged 40–59 years with a mix of both men and women participants, so we also explored how age and sex influenced the aforementioned associations (Table 5, and online Supplementary Fig. S1–S2). When stratifying by age, the associations were significant in patients aged 40–50 years rather than in those aged 50–59 years. In the subgroup analysis of sex, women participants had significant associations between dietary TAC and skeletal muscle mass. Therefore, women younger than 50 years may experience the best benefits from dietary TAC.

Table 2. Multivariate linear regression analysis of TAC and lean mass

	Appendicular relative lean mass (g/kg)									Trunk relative lean mass (g/kg)								
	Model 1			Model 2			Model 3			Model 1			Model 2			Model 3		
	β	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*
TAC	0·052	0·036, 0·068	< 0·001	0·029	0·018, 0·039	< 0·001	0·018	0·007, 0·029	< 0·001	0·026	0·013, 0·039	< 0·001	0·017	0·007, 0·026	< 0·001	0·014	0·004, 0·024	0·008
TAC quartiles																		
Q1	Ref			Ref			Ref			Ref			Ref			Ref		
Q2	4·948	1·098, 8·797	0·012	1·059	−1·327, 3·444	0·384	−0·036	−2·37, 2·266	0·976	3·962	0·924, 7·000	0·011	1·602	−0·635, 3·839	0·161	1·247	−0·948, 3·442	0·266
Q3	6·201	2·402, 10·001	0·001	5·778	3·413, 8·143	< 0·001	4·114	1·736, 6·492	< 0·001	3·806	0·808, 6·805	0·013	4·237	2·018, 6·455	< 0·001	3·931	1·664, 6·199	< 0·001
Q4	12·304	8·431, 16·177	< 0·001	6·807	4·374, 9·239	< 0·001	3·576	1·039, 6·113	0·006	6·619	3·563, 9·675	< 0·001	4·108	1·826, 6·390	< 0·001	3·087	0·667, 5·506	0·012
$P_{for\ trend}$	< 0·001			< 0·001			< 0·001			< 0·001			< 0·001			< 0·001		

	Total relative lean mass (g/kg)								
	Model 1			Model 2			Model 3		
	β	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*
TAC	0·082	0·053, 0·111	< 0·001	0·048	0·028, 0·067	< 0·001	0·035	0·014, 0·055	< 0·001
TAC quartiles									
Q1	Ref			Ref			Ref		
Q2	9·452	2·681, 16·223	0·006	3·046	−1·521, 7·612	0·191	1·752	−2·673, 6·177	0·438
Q3	11·008	4·324, 17·691	0·001	10·841	6·313, 15·369	< 0·001	9·153	4·581, 13·724	0·002
Q4	19·999	13·187, 26·811	< 0·001	11·655	6·998, 16·313	< 0·001	7·609	2·732, 12·487	0·002
$P_{for\ trend}$	< 0·001			< 0·001			< 0·001		

TAC, total antioxidant capacity.
Model 1: without adjustment.
Model 2: age, sex, race and socio-economic status were adjusted.
Model 3: Model 2 plus smoking, alcohol, physical activity, sedentary activity, protein, dietary fibre, Ca and phosphorus were adjusted.
β, 95 % CI, and *P* values are presented.

Table 3. Multivariate linear regression analysis of TAC and fat/BMI

	Total relevant fat (kg/kg)									Trunk relevant fat (kg/kg)								
	Model 1			Model 2			Model 3			Model 1			Model 2			Model 3		
	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P
TAC	−0·008	−0·011, −0·005	< 0·001	−0·005	−0·007, −0·003	< 0·001	−0·004	−0·006, −0·002	< 0·001	−0·009	−0·012, −0·006	< 0·001	−0·007	−0·009, −0·004	< 0·001	−0·005	−0·007, −0·002	< 0·001
TAC quartiles																		
Q1	Ref			Ref			Ref			Ref			Ref			Ref		
Q2	−0·957	−1·652, −0·262	0·007	−0·316	−0·795, 0·162	0·195	−0·202	−0·666, 0·261	0·392	−0·686	−1·363, −0·010	0·047	−0·309	−0·872, 0·255	0·283	−0·152	−0·697, 0·393	0·585
Q3	−1·168	−1·854,−0·482	< 0·001	−1·152	−1·626, −0·677	< 0·001	−1·011	−1·490, −0·532	< 0·001	−1·454	−2·122, −0·786	< 0·001	−1·525	−2·083, −0·966	< 0·001	−1·304	−1·867, −0·741	< 0·001
Q4	−2·048	−2·747, −1·349	< 0·001	−1·209	−1·697, −0·721	< 0·001	−0·832	−1·343, −0·320	0·001	−2·017	−2·697, −1·336	< 0·001	−1·545	−2·120, −0·971	< 0·001	−1·004	−1·605, −0·403	0·001
$P_{for\ trend}$	< 0·001			< 0·001			< 0·001			< 0·001			< 0·001			< 0·001		

	BMI (kg/m^2)								
	Model 1			Model 2			Model 3		
	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P
TAC	−0·004	−0·006, −0·001	0·003	−0·003	−0·005, −0·001	0·008	−0·003	−0·006, −0·001	0·006
TAC quartiles									
Q1	Ref			Ref			Ref		
Q2	−0·068	−0·613, 0·478	0·808	−0·008	−0·534, 0·551	0·976	−0·114	−0·650, 0·422	0·677
Q3	−0·654	−1·192, −0·115	0·017	−0·502	−1·040, 0·036	0·068	−0·786	−1·340, −0·233	0·005
Q4	−0·989	−1·507, −0·410	< 0·001	−0·817	−1·370, −0·263	0·004	−0·924	−1·514, −0·333	0·002
$P_{for\ trend}$	< 0·001			< 0·001			< 0·001		

TAC, total antioxidant capacity.
Model: without adjustment.
Model 2: age, sex, race and socio-economic status were adjusted.
Model 3: Model 2 plus smoking, alcohol, physical activity, sedentary activity, protein, dietary fibre, Ca and phosphorus were adjusted.
β, 95 % CI, and P values are presented.

Table 4. Saturation effect analysis of TAC on all outcomes

		< K			> K		
TAC turning point (K), mg VCE/100 g		β	95 % CI	P	β	95 % CI	P
Appendicular relative lean mass (g/kg)	67·433	0·077	0·035, 0·118	< 0·001	0·006	−0·008, 0·019	0·396
Trunk relative lean mass (g/kg)	64·072	0·071	0·029, 0·112	0·001	0·003	−0·009, 0·016	0·610
Total relative lean mass (g/kg)	64·809	0·171	0·087, 0·254	< 0·001	0·009	−0·017, 0·034	0·498
Total percent fat (kg/kg)	67·433	−0·018	−0·027, −0·010	< 0·001	−0·001	−0·003, 0·002	0·640
Trunk percent fat (kg/kg)	65·955	−0·025	−0·035, −0·015	< 0·001	−0·001	−0·004, 0·002	0·600
BMI (kg/m²)	71·167	−0·016	−0·025, −0·006	0·001	0·001	−0·004, 0·002	0·651

TAC, total antioxidant capacity.
Age, sex, race, socio-economic status, smoking, alcohol, physical activity, sedentary activity, protein, dietary fibre, Ca and phosphorus were adjusted.
β, 95 % CI, and *P* values are presented.

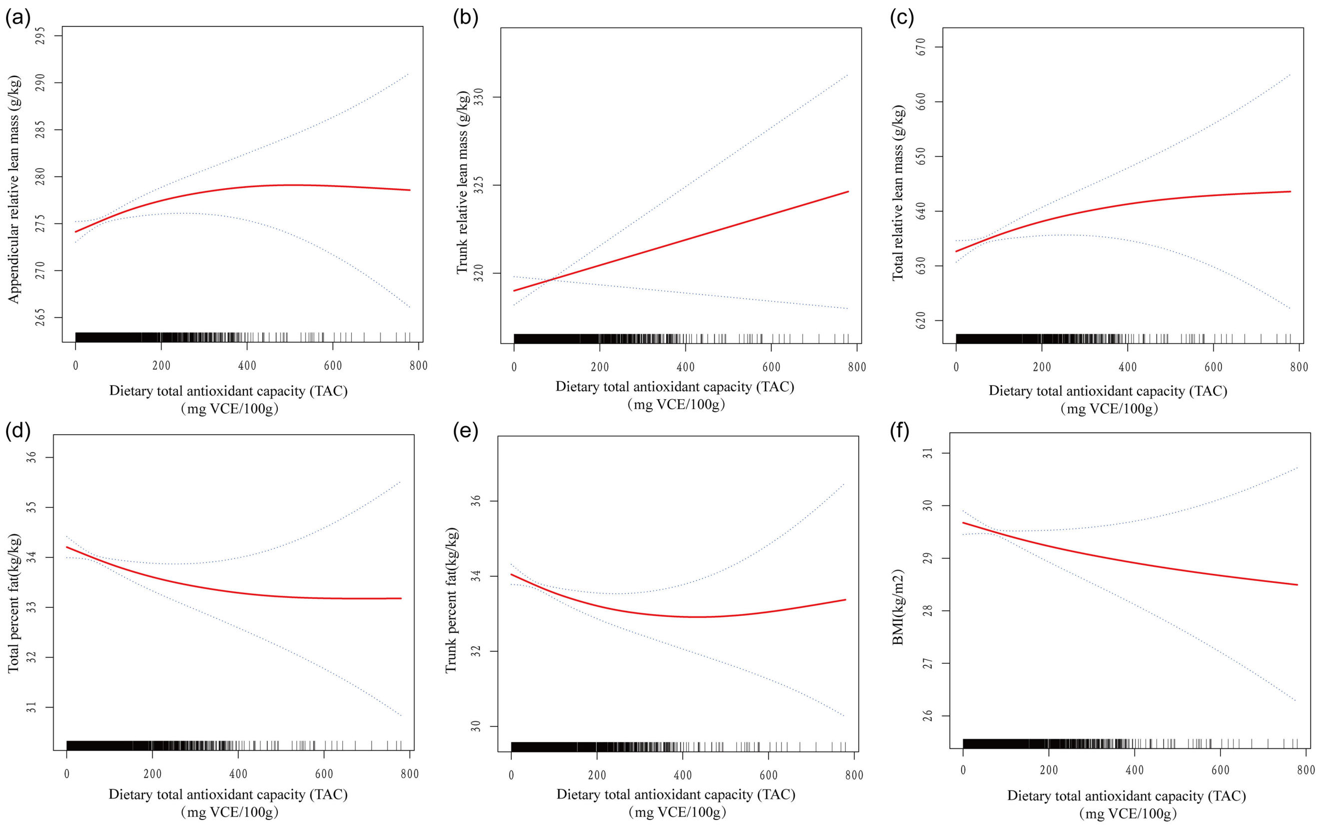

Fig. 2. Dose–response relationship between dietary TAC and skeletal muscle mass and body fat. (a) Appendicular relative lean mass (g/kg), (b) trunk relative lean mass (g/kg), (c) total relative lean mass (g/kg), (d) total percent fat (kg/kg), (e) trunk percent fat (kg/kg) and (f) BMI (kg/m²). TAC, total antioxidant capacity.

Discussion

The present analysis was conducted to determine the relationship between dietary TAC intake and body mass components in adults over 40 years old. The US population data were extracted from the NHANES database. The results showed that for adults who had an increased risk of skeletal muscle mass loss, higher dietary TAC is related to greater preservation of appendicular lean mass, trunk lean mass and total lean mass. Also, higher dietary TAC intake is associated with lower total percent fat, trunk percent fat and BMI.

To the best of our knowledge, the association between dietary TAC and skeletal muscle mass has not yet been investigated in a cohort with this size and scope[29,30]. Consistent with a previous cross-sectional study in cirrhotic outpatients, dietary TAC was positively associated with arm muscle area[6]. In a three-year-long cohort study, higher dietary antioxidant intake had positive effects on BMI and abdominal fat[10]. Another study of children and adolescents showed that dietary antioxidant intake had an inverse association with total body fat in obese subjects[11]. Above all,

Table 5. Association of dietary TAC with all outcomes stratified by age and sex

	Appendicular relative lean mass (g/kg)			Trunk relative lean mass (g/kg)			Total relative lean mass (g/kg)			Total percent fat (kg/kg)			Trunk percent fat (kg/kg)			BMI (kg/m²)		
	β	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*	*β*	95 % CI	*P*
Age (year)																		
≤ 50	0·023	0·008, 0·037	0·002	0·013	−0·000, 0·027	0·055	0·039	0·012, 0·066	0·005	−0·004	−0·007, −0·001	0·006	−0·006	−0·009, −0·002	0·001	−0·004	−0·008, −0·001	0·009
> 50	0·014	−0·000, 0·029	0·052	0·014	−0·000, 0·027	0·053	0·031	0·003, 0·058	0·032	−0·003	−0·006, −0·000	0·025	−0·004	−0·007, −0·001	0·022	−0·003	−0·006, 0·001	0·134
Sex																		
Men	0·007	−0·007, 0·021	0·322	0·006	−0·007, 0·019	0·350	0·014	−0·013, 0·040	0·308	−0·002	−0·004, 0·001	0·281	−0·003	−0·006, 0·000	0·067	−0·002	−0·005, 0·001	0·202
Women	0·032	0·017, 0·047	< 0·001	0·023	0·008, 0·037	0·002	0·061	0·032, 0·090	< 0·001	−0·006	−0·009, −0·003	< 0·001	−0·007	−0·011, −0·003	< 0·001	−0·005	−0·009, −0·002	0·003

TAC, total antioxidant capacity.
Race, socio-economic status, smoking, alcohol, physical activity, sedentary activity, protein, dietary fibre, Ca and phosphorus were adjusted.
β, 95 % CI, and *P* values are presented.

https://doi.org/10.1017/S0007114524002575 Published online by Cambridge University Press

dietary TAC intake has an inspiring effect on lean body mass, fat and BMI[31,32].

Although some studies have been deployed to detect the association between antioxidant intake and body components in particular populations, including children and adolescents, women, and healthy young adults, they not only primarily focused on the effects of single antioxidant intake, which might not fully explain the synergistic effects of all antioxidant vitamins in the diet[12], but also provide less knowledge of the middle-aged population who suffer a higher risk of skeletal muscle mass loss[33]. In this study, we paid attention to the comprehensive TAC values rather than considering the effects of single compounds, and we focused on the people who may experience greater benefits from the above results.

Although the underlying mechanisms between TAC and body composition were not elaborated in our study, by reviewing previously reported studies, we hypothesised that oxidative stress plays an integral role. Oxidative stress levels in skeletal muscle increase with age, which may lead to impaired muscle protein synthesis and muscle fibre damage[34,35]. Whereas, increased dietary TAC may protect muscles from damage by neutralising free radicals and reducing oxidative stress. In addition, antioxidants have anti-inflammatory effects and can reduce inflammatory responses in muscle tissue[36]. Inflammation is a known contributor to muscle atrophy; therefore, by reducing inflammation, a high TAC diet may help maintain muscle mass[37].

Dose–response curves suggest that all outcomes displayed a close correlation with dietary TAC. However, there also displayed a saturation effect of correlation between dietary TAC and skeletal muscle mass. All these results indicated that higher dietary TAC would likely improve lean body mass and decrease body fat and BMI. The saturation effect revealed that there was a threshold effect between dietary TAC and all outcomes. A subsequent subgroup analysis indicated that women and individuals aged 40–50 years will experience maximum benefits from higher dietary TAC on skeletal muscle mass. Our findings not only provide possible nutritional interventions for slowing or preventing the decline of muscle mass and function in middle-aged and older adults but also provide detailed recommendations for dietary intake in relation to the challenges of ageing regarding muscle loss and fat gain.

However, there are still some limitations in our study. First, this study was a cross-sectional design, which means that the causal relationship between dietary TAC and skeletal muscle mass could not be clearly determined owing to its original survey. Second, vitamin supplementation, such as vitamin C supplementation, is not taken into consideration while only focusing on dietary TAC intake in this design[38]. Finally, the bioavailability of dietary vitamins in participants was not included in this study because of the defect value in the NHANES dataset[39]. Furthermore, more work should be done to investigate the relationship between serum TAC levels and skeletal muscle mass both clinically and experimentally in the future to figure out their causal effect and potential mechanism.

In summary, our results found not only a simple linear positive association between TAC and lean body mass and a negative association between body fat but also a saturation threshold. This result is encouraging for enhancing health management of muscle loss and fat gain in middle-aged populations.

Supplementary material. For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114524002575

Acknowledgements. The authors gratefully acknowledge the contributions of all staffs who work on the National Health and Nutrition Examination Surveys.

None.

Conceptualisation: L. W. and S. C.; Methodology: J. Z. and W. F.; Software: J. Z. and W. F.; Formal Analysis: J. Z. and W. F.; Writing – Original Draft Preparation: J. Z. and W. F.; Writing – Review and Editing: L. W., J. Z. and W. F.; Supervision: L. W. All authors have read and approved the final manuscript.

The authors declare no conflicts of interest.

References

1. Frontera WR & Ochala J (2015) Skeletal muscle: a brief review of structure and function. *Calcif Tissue Int* **96**, 183–195.
2. Tanaka H, Shimizu N & Yoshikawa N (2017) Role of skeletal muscle glucocorticoid receptor in systemic energy homeostasis. *Exp Cell Res* **360**, 24–26.
3. Bear DE, Parry SM & Puthucheary ZA (2018) Can the critically ill patient generate sufficient energy to facilitate exercise in the ICU? *Curr Opin Clin Nutr Metab Care* **21**, 110–115.
4. Marzetti E, Hwang A-C, Tosato M, *et al.* (2018) Age-related changes of skeletal muscle mass and strength among Italian and Taiwanese older people: results from the Milan EXPO 2015 survey and the I-Lan Longitudinal Aging Study. *Exp Gerontol* **102**, 76–80.
5. Alcazar J, Aagaard P, Haddock B, *et al.* (2020) Age- and sex-specific changes in lower-limb muscle power throughout the lifespan. *J Gerontol A Biol Sci Med Sci* **75**, 1369–1378.
6. Al-Ozairi E, Alsaeed D, Alroudhan D, *et al.* (2021) Skeletal muscle and metabolic health: how do we increase muscle mass and function in people with type 2 diabetes? *J Clin Endocrinol Metab* **106**, 309–317.
7. Kaji H (2014) Interaction between muscle and bone. *J Bone Metab* **21**, 29–40.
8. Metter EJ, Talbot LA, Schrager M, *et al.* (2002) Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J Gerontol A Biol Sci Med Sci* **57**, B359–B365.
9. Rantanen T, Harris T, Leveille SG, *et al.* (2000) Muscle strength and body mass index as long-term predictors of mortality in initially healthy men. *J Gerontol A Biol Sci Med Sci* **55**, M168–M173.
10. Boengler K, Kosiol M, Mayr M, *et al.* (2017) Mitochondria and ageing: role in heart, skeletal muscle and adipose tissue. *J Cachexia Sarcopenia Muscle* **8**, 349–369.
11. Leitner LM, Wilson RJ, Yan Z, *et al.* (2017) Reactive oxygen species/nitric oxide mediated inter-organ communication in skeletal muscle wasting diseases. *Antioxid Redox Signal* **26**, 700–717.
12. Higgins MR, Izadi A & Kaviani M (2020) Antioxidants and exercise performance: with a focus on vitamin E and C supplementation. *Int J Environ Res Public Health* **17**, 8452.
13. Robinson SM, Reginster JY, Rizzoli R, *et al.* (2018) Does nutrition play a role in the prevention and management of sarcopenia? *Clin Nutr* **37**, 1121–1132.
14. Cruz-Jentoft AJ, Dawson Hughes B, Scott D, *et al.* (2020) Nutritional strategies for maintaining muscle mass and strength from middle age to later life: a narrative review. *Maturitas* **132**, 57–64.
15. Dekkers JC, van Doornen LJ & Kemper HC (1996) The role of antioxidant vitamins and enzymes in the prevention of exercise-induced muscle damage. *Sports Med* **21**, 213–238.
16. Nilsson MI, Mikhail A, Lan L, *et al.* (2020) A five-ingredient nutritional supplement and home-based resistance exercise improve lean mass and strength in free-living elderly. *Nutrients* **12**, 2391.
17. Gupta S, Finelli R, Agarwal A, *et al.* (2021) Total antioxidant capacity-relevance, methods and clinical implications. *Andrologia* **53**, e13624.
18. Bartosz G (2003) Total antioxidant capacity. *Adv Clin Chem* **37**, 219–292.
19. Lindschinger M, Tatzber F, Schimetta W, *et al.* (2019) A randomized pilot trial to evaluate the bioavailability of natural *v.* synthetic vitamin B complexes in healthy humans and their effects on homocysteine, oxidative stress, and antioxidant levels. *Oxid Med Cell Longev* **2019**, 6082613.

20. Prieto P, Pineda M & Aguilar M (1999) Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E. *Anal Biochem* **269**, 337–341.
21. Mazdak H, Tolou Ghamari Z & Gholampour M (2020) Bladder cancer: total antioxidant capacity and pharmacotherapy with vitamin-E. *Int Urol Nephrol* **52**, 1255–1260.
22. Fateh HL, Mirzaei N, Gubari MIM, *et al.* (2022) Association between dietary total antioxidant capacity and hypertension in Iranian Kurdish women. *BMC Womens Health* **22**, 255.
23. Han D, Chung M & Park Y (2022) Association of dietary total antioxidant capacity with cancer recurrence and mortality among breast cancer survivors: a prospective cohort study. *Nutr Cancer* **74**, 3253–3262.
24. de Freitas Lima L, de Faria Ghetti F, Hermsdorff HHM, *et al.* (2020) Dietary total antioxidant capacity is positively associated with muscular strength in cirrhotic outpatients: a cross-sectional study. *J Hum Nutr Diet* **33**, 78–85.
25. Wen W, Chen X, Huang Z, *et al.* (2022) Dietary lycopene supplementation improves meat quality, antioxidant capacity and skeletal muscle fiber type transformation in finishing pigs. *Anim Nutr* **8**, 256–264.
26. Qin X, Zhang T, Cao Y, *et al.* (2020) Effects of dietary sea buckthorn pomace supplementation on skeletal muscle mass and meat quality in lambs. *Meat Sci* **166**, 108141.
27. Floegel A, Kim D-O, Chung S-J, *et al.* (2010) Development and validation of an algorithm to establish a total antioxidant capacity database of the US diet. *Int J Food Sci Nutr* **61**, 600–623.
28. van Dronkelaar C, van Velzen A, Abdelrazek M, *et al.* (2018) Minerals and sarcopenia; the role of calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, and zinc on muscle mass, muscle strength, and physical performance in older adults: a systematic review. *J Am Med Dir Assoc* **19**, 6–11.
29. Ratajczak M, Skrypnik D, Bogdański P, *et al.* (2019) Effects of endurance and endurance-strength training on endothelial function in women with obesity: a randomized trial. *Int J Environ Res Public Health* **16**, 4291.
30. Lim SH, Fan SH & Say YH (2012) Plasma total antioxidant capacity (TAC) in obese Malaysian subjects. *Malays J Nutr* **18**, 345–354.
31. Besagil PS, Çalapkorur S & Şahin H (2020) Determination of the relationship between total antioxidant capacity and dietary antioxidant intake in obese patients. *Niger J Clin Pract* **23**, 481–488.
32. Amani R, Parohan M, Jomehzadeh N, *et al.* (2019) Dietary and biochemical characteristics associated with normal-weight obesity. *Int J Vitam Nutr Res* **89**, 331–336.
33. Bloom I, Shand C, Cooper C, *et al.* (2018) Diet quality and sarcopenia in older adults: a systematic review. *Nutrients* **10**, 308.
34. Luo J, Mills K, le Cessie S, *et al.* (2020) Ageing, age-related diseases and oxidative stress: what to do next? *Ageing Res Rev* **57**, 100982.
35. Yoshiko A, Shiozawa K, Niwa S, *et al.* (2024) Association of skeletal muscle oxidative capacity with muscle function, sarcopenia-related exercise performance, and intramuscular adipose tissue in older adults. *Geroscience* **46**, 2715–2727.
36. Kobayashi S, Murakami K, Sasaki S, *et al.* (2012) Dietary total antioxidant capacity from different assays in relation to serum C-reactive protein among young Japanese women. *Nutr J* **11**, 91.
37. Sumi K, Ashida K & Nakazato K (2020) Resistance exercise with anti-inflammatory foods attenuates skeletal muscle atrophy induced by chronic inflammation. *J Appl Physiol (1985)* **128**, 197–211.
38. Mansournia MA, Ostadmohammadi V, Doosti-Irani A, *et al.* (2018) The effects of vitamin D supplementation on biomarkers of inflammation and oxidative stress in diabetic patients: a systematic review and meta-analysis of randomized controlled trials. *Horm Metab Res* **50**, 429–440.
39. Platel K & Srinivasan K (2016) Bioavailability of micronutrients from plant foods: an update. *Crit Rev Food Sci Nutr* **56**, 1608–1619.