Q J Med 2013; **106**:809–821
doi:10.1093/qjmed/hct089 Advance Access Publication 8 May 2013

Original papers

QJM

Cardiorespiratory fitness in males, and upper limbs muscular strength in females, are positively related with 25-hydroxyvitamin D plasma concentrations in European adolescents: the HELENA study

J. VALTUEÑA[1,2], L. GRACIA-MARCO[3,4], I. HUYBRECHTS[5], C. BREIDENASSEL[1,6], M. FERRARI[7], F. GOTTRAND[8], J. DALLONGEVILLE[9], I. SIOEN[2,10], A. GUTIERREZ[11], M. KERSTING[12], A. KAFATOS[13], Y. MANIOS[14], K. WIDHALM[15], L.A. MORENO[4,16] and M. GONZÁLEZ-GROSS[1,6], ON BEHALF OF THE HELENA STUDY GROUP

From the [1]ImFine Research Group, Department of Health and Human Performance, Faculty of Physical Activity and Sport Sciences (INEF), Universidad Politécnica de Madrid, Avda/Martín Fierro 7, 28040, Madrid, Spain, [2]Department of Public Health, Faculty of Medicine, Ghent University, UZ 2 Block A, De Pintelaan 185, 9000 Ghent, Belgium, [3]CHERC (Chidren's Health and Exercise Research Centre) School of Sport and Health Sciences, University of Exeter, Heavitree Road, Exeter, EX1 2LU, United Kingdom, [4]GENUD Growth, Exercise, Nutrition and Development Research Group, University of Zaragoza, 42 Corona de Aragon 50009, Zaragoza, Spain, [5]Dietary Exposure Assessment Group, International Agency for Research on Cancer (IARC/WHO), 150 Cours Albert Thomas, 69372 Lyon CEDEX 08, France, [6]Institut für Ernährungs- und Lebensmittelwissenschaften - Humanernährung, Rheinische Friedrich-Wilhelms Universität Bonn, Endenicher Allee 11-13, AVZ 1, 5. Etage, 53115 Bonn, Germany, [7]National Research Institute on Food and Nutrition, Via Ardeatina, 546-00178 Roma, Italy, [8]Inserm U995, IFR114, University of Lille 2, 42, rue Paul Duez 59000 LILLE Lille, France, [9]Institut Pasteur de Lille & Inserm U 744 & Université Lille Nord de France, 1 rue de Pr Calmette, 59019 Lille Cedex, France, [10]Research Foundation—Flanders, Egmonstraat 5, 1000 Brussels, Belgium, [11]Department of Medical Physiology, School of Medicine, Granada University, Av de Madrid, 11, 18012, Granada, Spain, [12]Research Institute of Child Nutrition Dortmund, Rheinische Friedrich-Wilhelms-Universität Bonn, Heinstück 11, 44225 Dortmund, Germany, [13]Preventive Medicine and Nutrition Clinic, University of Crete School of Medicine, Iraclion, Crete, Argonafton 47, K.Ilioypolis,16346 Athens,Greece, [14]Department of Nutrition and Dietetics, Harokopio University, 70 El. Venizelou Ave., Kallithea, 17671, Athens, Greece, [15]Department of Pediatrics, Medical University of Vienna. A-1090 Vienna, Alserstr. 14, Austria and [16]Escuela Universitaria de Ciencias de la Salud, Departamento de Fisiatría y Enfermería, Universidad de Zaragoza, C/Domingo Miral s/n, 50009 Zaragoza España

Address correspondence to Dr J. Valtueña Santamaría, Departamento de Salud y Rendimiento Humano, Facultad de Ciencias de la Actividad Física y del Deporte-INEF, Universidad Politécnica de Madrid, C/ Martín Fierro, 7, 28040 Madrid, Spain. email: jara.valtuena@upm.es

Received 30 December 2012 and in revised form 6 March 2013

Summary

Background: High prevalence of vitamin D insufficiency (<75 nmol/l) has been previously reported in European adolescents. Vitamin D deficiency has been related to physical fitness and adiposity but it is not clearly known whether this relationship applies to growing children and adolescents.
Aim: To determine how body composition and physical fitness are related to 25-hydroxyvitamin D [25(OH)D] concentrations in European adolescents.
Design: The HEalthy Lifestyle in Europe by Nutrition in Adolescence-CSS study was a multi-centre cross-sectional study.
Methods: Plasma 25(OH)D, body composition and physical fitness measures were obtained in 1006 European adolescents (470 males) aged 12.5–17.5 years. Stepwise regression and ANCOVA were performed by gender using 25(OH)D as dependent variable, with body composition, physical fitness as independent variables controlling for age, seasonality and latitude.
Results: For males, maximum oxygen consumption (VO_{2max}) ($B = 0.189$) and body mass index (BMI) ($B = -0.124$) were independently associated with 25(OH)D concentrations (both $P < 0.05$). For females, handgrip strength ($B = 0.168$; $P < 0.01$) was independently associated with 25(OH)D concentrations. Those adolescents at lower BMI and high fitness score presented significant higher 25(OH)D concentrations than those at lower fitness score in the other BMI groups ($P < 0.05$).
Conclusions: Cardiorespiratory fitness and upper limbs muscular strength are positively associated with 25(OH)D concentrations in male and female adolescents, respectively. Adiposity in males and low fat free mass in females are related to hypovitaminosis D. The interaction between fitness and BMI has a positive effect on 25(OH)D concentrations. Therapeutic interventions to correct the high rates of vitamin D deficiency in adolescents should consider physical fitness.

Introduction

Vitamin D is essential for a vast number of physiologic processes, and thus adequate concentrations are necessary for advantageous optimal health. The knowledge of the role of vitamin D status in general health has increased in the last few years with the discovery of vitamin D receptors in multiple tissue types. Muscle and adipose tissue are among the first non-traditional vitamin D target organs identified.[1,2] Vitamin D is believed to stimulate muscle cell proliferation and growth.[3] Apart from bone metabolism, vitamin D also plays an important role in strengthening the immune system, improving cardiovascular health,[4] protecting against certain cancers and possibly even enhancing athletic performance.[1,5–7] In the last 10 years, its deficiency has been known to cause muscle weakness, hypotonia and prolonged time to peak muscle contraction, as well as prolonged time to muscle relaxation.[8]

Obesity, expressed as excess of body fat, also has an adverse effect on vitamin D status but this has been analysed mostly in adults.[9–11] Moreover, obese individuals only produce half the amount of vitamin D synthesized by non-obese individuals in response to sun exposure.[12]

Despite these evidences it is not clear whether this relationship applies to growing children and adolescents, and how low 25-hydroxyvitamin D [25(OH)D] concentration is associated with body composition and physical fitness. In adolescents, complications from vitamin D insufficiency are often late-onset rather than immediate, given that the majority of teenagers with vitamin D insufficiency are completely asymptomatic, and this fact complicates diagnosis.[7]

Previously we have reported a high prevalence of vitamin D deficiency in adolescents in Europe.[13,14] One of the main aims of the HEalthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study was to provide, for the first time, comparable data about micronutrient status in European adolescents. In the frame of a multi-analysis, vitamin D was identified as a potential conditional factor of physical fitness,[15] but body composition has not been considered. A deeper understanding of this relationship is needed in this population group.

Therefore, the purpose of this study is to determine how body composition, muscular strength and cardiorespiratory fitness interact with vitamin D status in healthy European adolescents. All the contributions to identify any factors that may be associated with low vitamin D concentrations may help public health authorities to optimize vitamin D status across Europe.

Subjects and methods

Subjects, recruitment and study design

The HELENA-CSS study was a multi-centre cross-sectional study aiming to obtain reliable and comparable data from a random sample of 3000

European adolescents aged between 12.5 and 17.5 years on a broad battery of nutrition and health-related parameters.[16] Subjects were recruited by a multi-stage random cluster sampling procedure, using schools as primary sampling units and classes as secondary sampling units. Criteria for city selection included geographic balance and presence of an experienced research group. The sample size was calculated according to stratified random sampling with proportional affixation to the size of the strata (SEX and AGE) and minimum variance (Neyman). A confidence level of 95% and the ±0.3 error in the worst of situations for the parameter body mass index (BMI) in the more general case of the study was chosen. On the city level, diversity of the sample with respect to cultural and socio-economic aspects was achieved by performing a random proportional distribution of all schools taking into account the site of the school (district/zone of the city) and the type of school (public or private). Exclusion criteria were limited to subjects who were not able to speak the local language, subjects participating simultaneously in another clinical trial, subjects aged <12.5 or >17.5 years and subjects having suffered from acute infection 1 week before the visit. Exclusions from the study were done a posteriori, without the knowledge of the affected subjects, to avoid non-desired situations. Therefore, whole classes were studied. The complete description of the design and implementation of the study has been described elsewhere.[17]

Within the sampling procedure, a random subgroup of ~1000 adolescents (target number, 100 in each city) was foreseen to participate in the blood sampling. Finally, 1089 adolescents conform the valid HELENA blood subsample. For the present work, a subset of 1006 adolescents (470 males and 536 females, mean age of 14.7 ± 1.2 years) had valid data on 25(OH)D concentrations. This subgroup was recruited between October 2006 and October 2007 in 10 cities of nine different European countries: Athens (Greece), Dortmund (Germany), Ghent (Belgium), Heraklion (Greece), Lille (France), Pecs (Hungary), Rome (Italy), Stockholm (Sweden), Vienna (Austria) and Zaragoza (Spain). The protocol was approved by the Human Research Review Committee of the Universities of Bonn (Dortmund), Lille, Rome, Zaragoza, Athens, Heraklion, Pecs, Ghent and Vienna. The study has been performed following the ethical guidelines of the Declaration of Helsinki 1964 (revision of Edinburgh 2000), Convention of Oviedo (1997), the Good Clinical Practice and the legislation about clinical research in humans in each of the participating countries. Informed written consent was obtained from subjects and parents or guardians. Complete description of ethical issues and good clinical practice within the HELENA-CSS is described elsewhere.[18]

Specimen collection and biochemical analyses

Fasting blood samples were collected by venipuncture at school between 8 and 10 o'clock in the morning from November 2006 to October 2007, during the whole academic year, excluding the summer period. For the measurement of vitamin D, blood was collected in EDTA tubes transported at room temperature to the central laboratory at University of Bonn (IEL) within 24 h. There it was centrifuged at 3500 rpm for 15 min at 4°C and the supernatant stored at −80°C until assayed. The complete methodology has been described elsewhere.[19]

Plasma or serum concentrations of 25(OH)D are considered to be the most reliable measure of overall vitamin D status and thus can be used to assess the vitamin D status.[20] Plasma 25(OH)D was analysed by ELISA using a kit (OCTEIA 25-Hydroxy Vitamin D) from Immunodiagnostic System (Germany) and measured with a Sunrise™ Photometer by TECAN (Germany). The IDS OCTEIA 25-Hydroxy Vitamin D kit is an enzyme immunoassay intended for the quantitative determination of 25(OH)D and other hydroxylated metabolites in human serum or plasma. Results are to be used in conjunction with other clinical and laboratory data to assist the clinician in the assessment of vitamin D sufficiency.[20] The sensitivity of this method is 5 nmol/l 25(OH)D, and the variation is below 6%. The mean recovery of 25(OH) D is 101%. The CV for the method was below 1%. The optimal concentrations for 25(OH)D were established at ⩾75 nmol/l, following international guidelines.[20,21]

Seasonality

The variable 'blood drawing date' was used to compute seasonality defined as following and similar to previous studies[22]: winter (1; January through March), spring (2; April through June) and autumn (3; October through December). Blood drawing was performed only during the academic year. The complete methodology of the sampling calendar procedure has been described elsewhere.[22]

Latitude

The latitude was also taken into account as a confounder in the analyses. The latitude of each city was obtained from http://maps.google.es/. Latitudes of the involved cities were: Stockholm (59°33′ N), Athens (37°98′ N), Heraklion (35°33′ N), Rome (41°89′ N), Zaragoza (41°66′ N), Pecs (46°07′ N), Ghent (51°06′ N), Lille (50°63′ N), Dortmund

(51°51′ N) and Vienna (48°21′ N). To make use of this data, latitudes were added to the database as numeric variables with two decimals (i.e. Stockholm = 59.55) as previously described.[15]

Anthropometric measurements

The complete description of anthropometric measures was described elsewhere.[23] Adolescents had their height and weight measured by trained researchers in a standardized way in light clothing and without shoes. The weight was recorded to the nearest 0.1 kg, using an electronic scale (Type SECA 861, UK). The height of the adolescents was recorded to the nearest 0.1 cm, using a telescopic height measuring instrument (Type SECA 225, UK). The BMI of the adolescents was calculated from their measured height and weight [BMI = weight divided by height squared (kg/m^2)]. International age- and gender-specific cut-off points[24,25] were used to assess BMI categories (underweight/normal weight/overweight/obese). Fat mass (FM) and fat free mass (FFM) were assessed my means of a classical tetrapolar technique (BIA 101 AKERN SRL, Pontassieve, FI, Italy). An index for these parameters was created (FMI and FFMI) dividing the mass of each one by the square of the height. Subjects were classified in tertiles according to their body composition, males and females separately.

Physical fitness

The health-related physical fitness components (i.e. cardiorespiratory fitness (CRF) and muscular fitness) were assessed by the physical fitness tests from the Eurofit battery, described elsewhere.[26] The scientific rationale for the selection of all of these tests, as well as their reliability in young people, has been previously published.[27] In brief, all the tests were performed twice, and the best score was retained, except the '20 m shuttle run' test, which was performed only once. Upper body muscular strength was assessed with the 'handgrip' test (kg). Lower body muscular strength was assessed with the 'standing long jump' test (cm). Cardiorespiratory fitness was assessed with the '20 m shuttle run' test (stage). A stage is the period of time in which the speed maintains constant. In this test, the initial speed is 8.5 km/h, which is increased by 0.5 km/h/min (1 min equals one stage).[28] Léger equation was used to estimate the maximum oxygen consumption (VO_{2max}) from 20 m shuttle run test.[29]

Subjects were classified in tertiles according to their fitness tests results from 1 (worst result) to 3 points (best result), stratified by gender.

Statistical analysis

Descriptive values are shown as mean + standard deviation, unless otherwise stated. Independent samples *T*-test was used to analyse differences of 25(OH)D between sexes. Pearson's correlation coefficients were computed between 25(OH)D concentrations, body composition and fitness tests.

Stepwise multivariate linear regression was selected as a way of choosing predictors of a particular dependent variable on the basis of statistical criteria. It was conducted to examine the independent associations of body composition (BMI *z*-score, FMI and FFMI) and physical fitness (muscular strength and cardiorespiratory fitness) on 25(OH)D concentrations by sex, taking 25(OH)D concentrations as dependent variable. Each model always retained age, seasonality and latitude as confounders (Model 0), and all body composition and fitness tests were entered together into a stepwise regression model. The contribution of each variable to the variance of 25(OH)D concentrations is explained by adjusted R^2 in Table 3. It gives the most useful measure of the success of our model ($R^2 \times 100$ as a percentage of the variance). Variables first entered in the model are the ones more related with 25(OH)D concentrations. Following variables give an additional value in order of appearance, explaining the variance of 25(OH)D concentrations. The beta value (β) is the measure of how strongly each predictor variable influences 25(OH)D concentrations. Thus, the higher the beta value the greater the impact of the predictor variable on the criterion variable. Correlation between predictive values and 25(OH)D concentrations was also given by *R* in Table 3.

ANCOVA was performed to analyse the differences in 25(OH)D concentrations according to the tertiles of body composition and physical fitness (mean and standard error). Age, seasonality and latitude were included as covariates.

All analyses were performed using the Statistical Package for Social Sciences software (SPSS, version 15.0 for WINDOWS; SPSS, Chicago, IL, USA), and values of $P < 0.05$ were considered statistically significant. Figures were performed using Sigmaplot (version 10.0 for WINDOWS; Systat Software, San José, CA, USA).

Results

Table 1 includes descriptive characteristics of the sample split by sex. Males presented higher FFMI and physical fitness performance than girls ($P < 0.001$). On the contrary, females had higher FMI compared with males ($P < 0.001$). The mean

Table 1 Descriptive characteristics of the study sample

	All ($n = 1006$)		Male ($n = 470$)		Female ($n = 536$)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	14.87	1.19	14.85	1.21	14.88	1.17
Height (cm)	165.77	9.33	170.15	9.71	161.93	7.01
Weight (kg)	58.99	12.33	62.14	13.69	56.23	10.24
BMI (kg/m^2)	21.37	3.57	21.33	3.76	21.40	3.39
Body fat percentage	23.49	9.35	19.97	10.73	26.33	6.87
FM index(kg/m^2)*	5.27	2.99	4.59	3.44	5.82	2.44
FFM index(kg/m^2)*	16.80	1.78	17.84	1.80	15.89	1.15
Handgrip (kg)*	30.61	8.80	36.06	9.22	25.93	4.86
Standing long jump (cm)*	162.74	34.86	183.98	32.43	144.51	25.23
20 m shuttle run (stage)*	4.82	2.76	6.37	2.77	3.36	1.77
VO_{2max} Léger (ml/kg/min)*	40.13	7.85	44.44	7.72	36.07	5.43
25(OH)D (nmol/l)	58.80	23.08	57.44	22.67	59.99	23.40

*Significant differences between sexes; $P < 0.05$.
FM index, fat mass index; FFM index, fat free mass index; 20 m shuttle run, cardiorespiratory fitness; VO_{2max} léger, maximal oxygen consumption. Results are showed as mean ± SD.

Table 2 Pearson correlation coefficients between the 25(OH)D concentration and body composition and physical fitness

	25(OH)D (nmol/l)	
	Males	Females
Age (years)	0.011	0.181**
Height (cm)	0.021	0.120**
Weight (kg)	−0.057	0.068
BMI (kg/m^2)	−0.082	0.013
Body fat percentage	−0.058	0.024
FM index(kg/m^2)	−0.064	0.014
FFM index(kg/m^2)	−0.088	0.040
Handgrip (kg)	−0.029	0.116**
Standing broad jump(cm)	0.077	0.085
VO_{2max} léger (ml/kg/min)	0.108*	0.022

*Correlation is significant at the 0.05 level (two-tailed); **correlation is significant at the 0.01 level (two-tailed).

values of 25(OH)D concentrations were under the optimal concentrations (<75 nmol/l) for both males and females (57.44 ± 22.67 and 59.99 ± 23.40 nmol/l, respectively).

Pearson's correlation coefficients for the variables involved in this study are shown on Table 2. In males, VO_{2max} ($r = 0.108$) was positively correlated with 25(OH)D ($P < 0.05$). In females, handgrip strength ($r = 0.116$), age ($r = 0.181$) and height ($r = 0.120$) were positively correlated with 25(OH)D (all $P < 0.01$).

Table 3 shows the results from the stepwise multivariate linear regression analysis stratified by gender. For males, linear regression of 25(OH)D showed that VO_{2max} and BMI ($B = 0.189$; $P < 0.01$, $B = -0.125$; $P < 0.05$, respectively) were independently associated with 25(OH)D concentrations after controlling for seasonality, latitude and age, explaining the 24.3% of the variance. For females, only handgrip strength ($B = 0.168$; $P < 0.01$) was independently associated with 25(OH)D concentrations after controlling for the same factors and explaining the 20.3% of the variance.

Figure 1 shows 25(OH)D concentrations according to body composition variables adjusted for age, seasonality and latitude. In males, the lower the FFMI the higher the 25(OH)D concentrations ($P < 0.01$). In females, no significantly differences were found.

Figure 2 shows 25(OH)D concentrations according to muscular strength and CRF adjusted for age, seasonality and latitude. In males, the higher the performance in standing long jump the higher the 25(OH)D concentration ($P < 0.05$).

Figure 3 shows 25(OH)D concentrations according to BMI and fitness score by sex, adjusted for age, seasonality and latitude. In both males and females, those subjects at lower BMI and high fitness score presented significantly higher 25(OH)D concentrations than those at lower fitness score and than the other BMI groups ($P < 0.05$).

Discussion

There is more and more evidence that vitamin D status is associated to other health-related factors beyond skeletal metabolism.[6,7] High prevalence

Table 3 Stepwise multiple regression model for 25(OH)D (nmol/l) as dependent variable stratified by gender

25(OH)D concentrations (nmol/l)									
	Males, $N = 342$					Females, $N = 390$			
	β	Partial corr.	P-value	R^2		β	Partial corr.	P-value	R^2
Model 1				0.231	Model 1				0.203
VO_{2max} (ml/kg/min)	0.189	0.174	0.002		Handgrip (kg)	0.168	0.157	0.002	
Model 2				0.243					
VO_{2max} (ml/kg/min)	0.158	0.143	0.009						
BMI	−0.125	−0.124	0.023						

Age, seasonality (winter = 1, spring = 2 and autumn = 3) and latitude. (Model 0) was additionally entered as covariates in all the models. All body composition and fitness variables were entered together into a stepwise regression model.

rates (80%) of insufficiency have been identified in Europe among adolescents within the HELENA study.[13] It is now important to understand factors influencing these low vitamin D concentrations found, to contribute to public health authorities to optimize vitamin D status across Europe. Therefore, there is a need to get deeper into the relationship of vitamin D with two important health markers as physical fitness and body composition in growing children and adolescents.

Our main results reveal that VO_{2max} (positively) and BMI (negatively) are independently associated with 25(OH)D concentrations in males, after controlling for a relevant set of confounders, whereas handgrip strength as a measure of muscular strength, is positively associated with 25(OH)D concentrations in females. Regarding the ANCOVA results, the lower the FFMI and the performance in standing long jump, the higher the 25(OH)D concentrations in males. In both males and females, the interaction between fitness and BMI has a significant positive effect on 25(OH)D concentrations.

Low serum 25(OH)D levels could be associated with a number of adverse outcomes in the human musculoskeletal, innate immune and cardiovascular systems.[30]

Moreover, both cardiovascular and muscular fitness have been previously reported as strong predictors of health.[31] Strong evidence was found indicating that higher levels of cardiorespiratory fitness in childhood and adolescence are associated with a healthier cardiovascular profile later in life. Muscular strength improvements from childhood to adolescence are negatively associated with changes in overall adiposity. In addition, a healthier body composition in childhood and adolescence is associated with a healthier cardiovascular profile later in life and with a lower mortality risk. Those parameters should be taken together into account when analysing nutritional deficiencies in adolescence.

There are several studies in the literature assessing vitamin D status in children and adolescents but mainly focused on physical activity rather than physical fitness. In addition, not only BMI but also FM and FFM have been included in our study, which according to the literature are more appropriate for the growing period.[7,32] Our results show that BMI and percentage of body fat in males are negatively associated with 25(OH)D concentrations. This reduction in 25(OH)D concentrations with increased adiposity is assumed to be due to enhanced sequestration of vitamin D in fat tissue.[33] Vitamin D affects lipolysis and adipogenesis in human adipocytes through its role in regulating intracellular calcium concentrations and could then influence adiposity deposition. Vitamin D deficiency has been associated with different components of the metabolic syndrome. Garanty-Bogacka *et al.* stated that hypovitaminosis D, common in obese adolescents at risk for type 2 diabetes (older age, puberty, *Acanthosis nigrans*), is associated with worse insulin resistance.[34]

In a longitudinal study, vitamin D deficient children had an adjusted 0.1 per year greater change in BMI compared with vitamin D sufficient children (P for trend = 0.05). Similarly, vitamin D deficient children had a 0.03 per year (95% CI 0.01–0.05) greater change in the subscapular-to-triceps skinfold thickness ratio and a 0.8-cm/year (95% CI 0.1–1.6 cm/year) greater change in waist circumference compared with vitamin D sufficient children. These findings support the role of vitamin D in body fat deposition.[35]

In the same direction of our results, Alemzadeh *et al.*[36], Cheng *et al.*[37] and Rajakumar *et al.*[38] reported that the prevalence of vitamin D deficiency was 3-fold higher in those with high BMI and

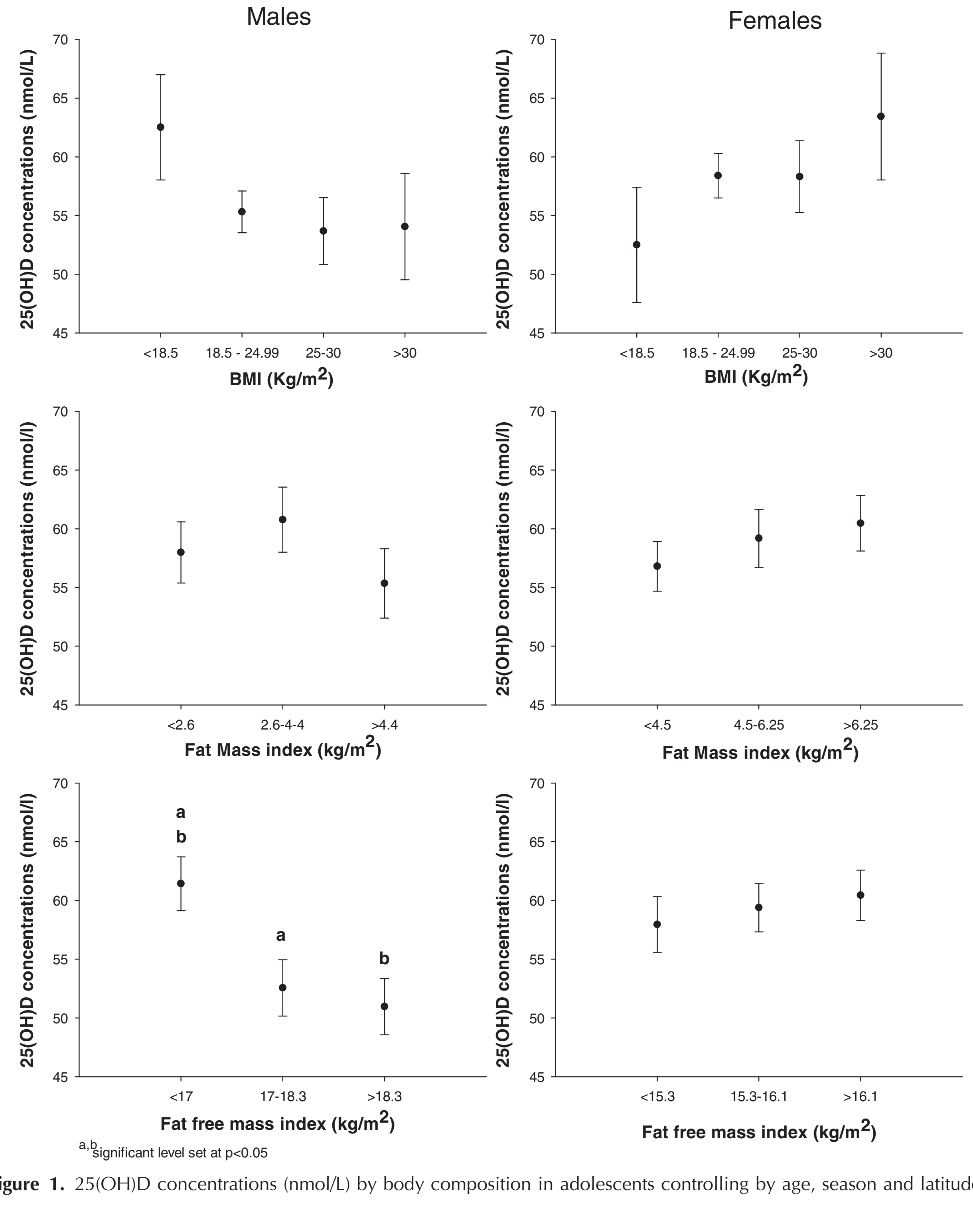

Figure 1. 25(OH)D concentrations (nmol/L) by body composition in adolescents controlling by age, season and latitude.

adiposity.[36] In Europe, Smotkin-Tangorra *et al.*[39] also found an inverse correlation between 25(OH)D concentrations and BMI.[39]

There are contrary results for females with an increase in 25(OH)D concentrations according to BMI increase. Foo *et al.*[40] reported similar results for Chinese adolescent girls.[40] In contrast, other studies did not find any associations of BMI with 25(OH)D concentrations in the paediatric population.[41–43] These controversial results with BMI led to consider not only the use of BMI but also the use of percentage of body fat and FFM to assess body composition in this population group.[44,45] Our results reveal that FFM and upper limb strength positively correlate

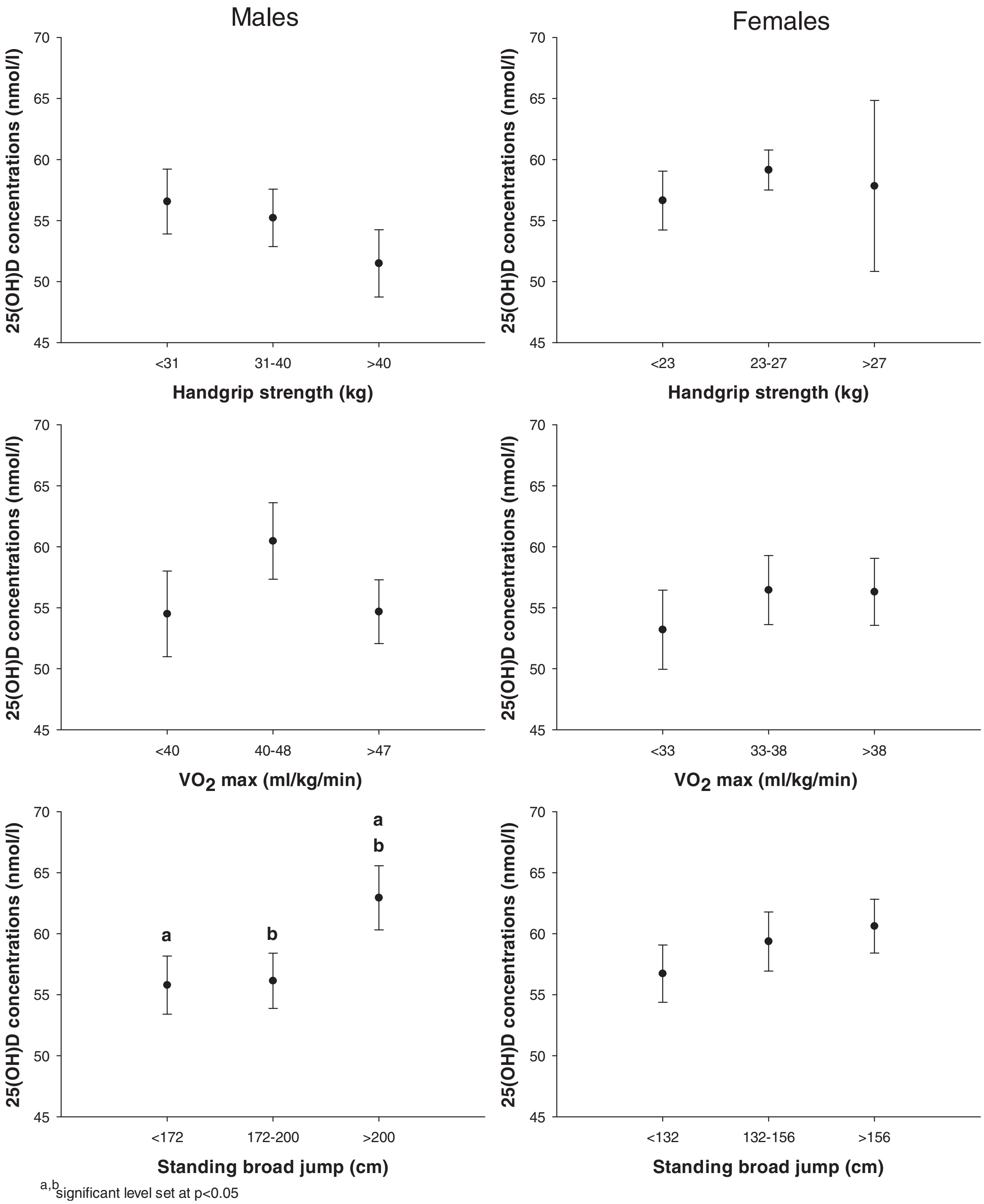

Figure 2. 25(OH)D concentrations (nmol/L) by muscular and cardiorespiratory fitness in adolescents controlling by age, season and latitude.

with 25(OH)D concentrations in females. In agreement, Foo *et al.*[40] observed same correlations in girls. Skeletal muscles require vitamin D for maximum function, with deficiency causing muscle weakness.[30] In agreement with our results, positive relationship between vitamin D and muscle strength was recently observed in apparently healthy adolescent girls from the UK.[46] Our data reinforce the observation made by Stewart *et al.*,[47] along with many other studies in children, providing compelling evidence that vitamin D is indeed, together with testosterone, the other steroid hormone that is important for muscle function and strength.[47]

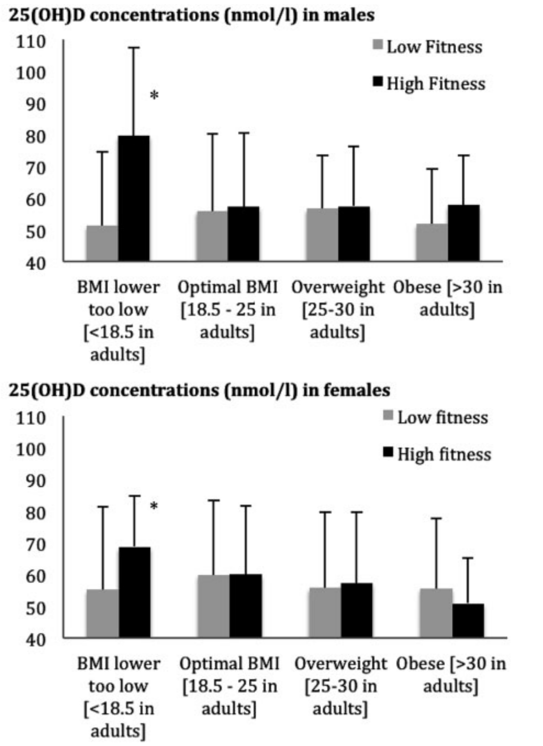

Figure 3. 25(OH)D concentrations according to BMI and fitness score for males and females controlling by age, season and latitude.

**P<0.05 between high fitness score group for the BMI lower and the rest of the groups.*

Our results show that vitamin D status is related not only with muscle strength but also with cardiovascular fitness. In males, cardiorespiratory fitness positive correlates with 25(OH)D concentrations. Inspection of the recent vitamin D epidemiological literature has brought to light the potential inverse relation of 25(OH)D concentrations with cardiovascular diseases.[48]

Similar to our results, in a recent study made in German adolescents, Lämmle *et al.*[49] reported that lower 25(OH)D levels are associated with lower endurance performance and a higher BMI. Racinais *et al.* [22] also found in apparently healthy adolescents from Qatar also found that the severely vitamin D deficient group had lower aerobic fitness than the moderately deficient group. In agreement, Zittermann *et al.*[50] demonstrated an association between low vitamin D status and exercise intolerance.

These results together with those in the regression model suggest that physical fitness highly influences 25(OH)D concentrations in adolescents. This is one of the first studies dealing with objectively measured physical fitness tests rather than with physical activity (PA) questionnaires. These findings are of great interest for public health. The presence of abundant vitamin D receptors in myocardial tissue and vasculature and the observation that cardiovascular health may be ameliorated with sufficient vitamin D suggest a greater role of vitamin D in the cardiovascular system than expected.[50]

Regarding our results, a relationship between physical fitness and vitamin D concentrations is established. However, cross-sectional studies cannot determine the direction of this relationship, due to a higher vitamin D status could be caused by increased physical fitness and outdoor sun exposure (1) or a higher vitamin D status could lead to an increase in physical fitness (3).

Although we controlled for several potential confounders, data on testosterone were not available, and we cannot be certain that other unmeasured confounders have not influenced our observations. It should also be considered that sexual maturation was not included as a covariate in our analyses, due to the fact that most of the adolescents were at tanner 4 and 5. However, the age of the adolescents was used instead, which showed a slight and stronger association with the dependent variables.

Despite the aforementioned limitation, the HELENA study has several strengths. The sampling procedure and the strict standardization of the field work among the countries involved in the study avoided to a great extent the kind of confounding bias due to inconsistent protocols and different laboratory methods which makes comparing results from isolated studies difficult. The main contribution of our study is the use of a large pool of variables, which provide a deeper understanding of the relationship between vitamin D status, body composition and physical fitness in European adolescents. The majority of the studies only assess PA and BMI but not fitness nor FFM and FM in relation to vitamin D, which is an additional strength of our work. The fitness tests used in the present report showed a good criterion-related validity in adolescents.[27] In addition, this study includes important sets of confounders, i.e. age, seasonality or latitude which is crucial to analyse the association.

In conclusion, cardiorespiratory fitness is positively associated with 25(OH)D concentrations in male adolescents, whereas upper limbs muscular strength is positively associated with 25(OH)D concentrations in young females. In a similar way, higher FM in males and lower FFM in females are related to hypovitaminosis D. In both males and females, the interaction between fitness and BMI has a significant positive effect on 25(OH)D concentrations. Lifestyle and appropriate nutrition may prevent the long-term effect of hypovitaminosis D on health beyond mineral and bone metabolism. Therapeutic interventions to correct the high rates of vitamin D deficiency in adolescents should consider muscular and cardiorespiratory physical fitness.

Acknowledgements

Many thanks to Adelheid Schuch for her contribution to laboratory work and to Laura Barrios for statistical assistance. Helena Study Group: Co-ordinator: Luis A. Moreno; Core group members: Luis A. Moreno, Fréderic Gottrand, Stefaan De Henauw, Marcela González-Gross and Chantal Gilbert; Steering Committee: Anthony Kafatos (President), Luis A. Moreno, Christian Libersa, Stefaan De Henauw, Jackie Sáchez, Fréderic Gottrand, Mathilde Kesting, Michael Sjostrom, Dénes Molnár, Marcela González-Gross, Jean Dallongeville, Chantal Gilbert, Gunnar Hall, Lea Maes and Luca Scalfi. Project Manager: Pilar Meléndez. 1. Universidad de Zaragoza (Spain): Luis A. Moreno, Jesús Fleta, José A. Casajús, Gerardo Rodríguez, Concepción Tomás, María I. Mesana, Germán Vicente-Rodríguez, Adoración Villarroya, Carlos M. Gil, Ignacio Ara, Juan Revenga, Carmen Lachen, Juan Fernández Alvira, Gloria Bueno, Aurora Lázaro, Olga Bueno, Juan F. León, Jesús M[a] Garagorri, Manuel Bueno, Juan Pablo Rey López, Iris Iglesia, Paula Velasco, Silvia Bel, Luis Gracia-Marco and Theodora Mouratidou. 2. Consejo Superior de Investigaciones Científicas (Spain): Ascensión Marcos, Julia Wärnberg, Esther Nova, Sonia Gómez, Esperanza Ligia Díaz, Javier Romeo, Ana Veses, Mari Angeles Puertollano, Belén Zapatera and Tamara Pozo. 3. Université de Lille 2 (France): Laurent Beghin, Christian Libersa, Frédéric Gottrand, Catalina Iliescu and Juliana Von Berlepsch. 4. Research Institute of Child Nutrition Dortmund, Rheinische Friedrich-Wilhelms-Universität Bonn (Germany): Mathilde Kersting, Wolfgang Sichert-Hellert and Ellen Koeppen. 5. Pécsi Tudományegyetem (University of Pécs) (Hungary): Dénes Molnar, Eva Erhardt, Katalin Csernus, Katalin Török, Szilvia Bokor, Mrs. Angster, Enikö Nagy, Orsolya Kovács and Judit Repásy. 6. University of Crete School of Medicine (Greece): Anthony Kafatos, Caroline Codrington, María Plada, Angeliki Papadaki, Katerina Sarri, Anna Viskadourou, Christos Hatzis, Michael Kiriakakis, George Tsibinos, Constantine Vardavas Manolis Sbokos, Eva Protoyeraki and Maria Fasoulaki. 7. Institut für Ernährungs- und Lebensmittelwissenschaften—Ernährungphysiologie. Rheinische Friedrich Wilhelms Universität (Germany): Peter Stehle, Klaus Pietrzik, Marcela González-Gross, Christina Breidenassel, Andre Spinneker, Jasmin Al-Tahan, Miriam Segoviano, Anke Berchtold, Christine Bierschbach, Erika Blatzheim, Adelheid Schuch and Petra Pickert. 8. University of Granada (Spain): Manuel J. Castillo, Ángel Gutiérrez, Francisco B. Ortega, Jonatan R Ruiz, Enrique G. Artero, Vanesa España-Romero, David Jiménez-Pavón and Palma Chillón. 9. Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione (Italy): Davide Arcella, Elena Azzini, Emma Barrison, Noemi Bevilacqua, Pasquale Buonocore, Giovina Catasta, Laura Censi, Donatella Ciarapica, Paola D'Acapito, Marika Ferrari, Myriam Galfo, Cinzia Le Donne, Catherine Leclercq, Giuseppe Maiani, Beatrice Mauro, Lorenza Mistura, Antonella Pasquali, Raffaela Piccinelli, Angela Polito, Raffaella Spada, Stefania Sette and Maria Zaccaria. 10. University of Napoli 'Federico II' Dept of Food Science (Italy): Luca Scalfi, Paola Vitaglione and Concetta Montagnese. 11. Ghent University (Belgium): Ilse De Bourdeaudhuij, Stefaan De Henauw, Tineke De Vriendt, Lea Maes, Christophe Matthys, Carine Vereecken, Mieke de Maeyer, Charlene Ottevaere and Inge Huybrechts. 12. Medical University of Vienna (Austria): Kurt Widhalm, Katharina Phillipp and Sabine Dietrich. 13. Harokopio University (Greece): Yannis Manios, Eva Grammatikaki, Zoi Bouloubasi, Tina Louisa Cook, Sofia Eleutheriou, Orsalia Consta, George Moschonis, Ioanna Katsaroli, George Kraniou, Stalo Papoutsou, Despoina Keke, Ioanna Petraki, Elena Bellou, Sofia Tanagra, Kostalenia Kallianoti, Dionysia Argyropoulou, Katerina Kondaki, Stamatoula Tsikrika and Christos Karaiskos. 14. Institut Pasteur de Lille (France): Jean Dallongeville and Aline Meirhaeghe. 15. Karolinska Institutet (Sweden): Michael Sjöstrom, Patrick Bergman, María Hagströmer, Lena Hallström, Mårten Hallberg, Eric Poortvliet, Julia Wärnberg, Nico Rizzo, Linda Beckman, Anita Hurtig Wennlöf, Emma Patterson, Lydia Kwak, Lars Cernerud, Per Tillgren and Stefaan Sörensen. 16. Asociación de Investigación de la Industria Agroalimentaria (Spain): Jackie Sánchez-Molero, Elena Picó, Maite Navarro, Blanca Viadel, José Enrique Carreres, Gema Merino, Rosa Sanjuán, María Lorente, María José Sánchez and Sara Castelló. 17. Campden & Chorleywood Food Research Association (UK): Chantal Gilbert, Sarah Thomas, Elaine Allchurch and Peter Burguess. 18. SIK—Institutet foer Livsmedel och Bioteknik (Sweden): Gunnar Hall, Annika Astrom, Anna Sverkén and Agneta Broberg. 19. Meurice Recherche & Development asbl (Belgium): Annick Masson, Claire Lehoux, Pascal Brabant, Philippe Pate and Laurence Fontaine. 20. Campden & Chorleywood Food Development Institute (Hungary): Andras Sebok, Tunde Kuti and

Adrienn Hegyi. 21. Productos Aditivos SA (Spain): Cristina Maldonado and Ana Llorente. 22. Cárnicas Serrano SL (Spain): Emilio García. 23. Cederroth International AB (Sweden): Holger von Fircks, Marianne Lilja Hallberg and Maria Messerer. 24. Lantmännen Food R&D (Sweden): Mats Larsson, Helena Fredriksson, Viola Adamsson and Ingmar Börjesson. 25. European Food Information Council (Belgium): Laura Fernández, Laura Smillie and Josephine Wills. 26. Universidad Politécnica de Madrid (Spain): Marcela González-Gross, Jara Valtueña, David Jiménez-Pavón, Ulrike Albers, Raquel Pedrero, Agustín Meléndez, Pedro J. Benito, Juan José Gómez Lorente, David Cañada, Alejandro Urzanqui, Juan Carlos Ortiz, Francisco Fuentes, Rosa María Torres and Paloma Navarro. M.G.G., L.A.M., M.K., F.G., J.D., A.K., Y.M., M.F. and K.W. designed the HELENA study and conducted research (recruitment of adolescents, data collection and blood sampling); J.V., C.B., conducted research and performed blood analysis; J.V., M.G.G., L.G.M. and I.H. performed the statistical analysis; J.V., M.G.G. and L.A.M. wrote the paper. J.V., I.H., M.G.G. participated in the data interpretation. J.V., A.G. and I.S. participated in the literature search. J.V., M.G.G. and L.A.M. had primary responsibility for final content. All authors read and approved the final manuscript.

Funding

The HELENA study has taken place with the financial support of the European Community Sixth RTD Framework Programme (Contract FOOD-CT-2005-007034). The content of this article reflects only the authors' views, and the European Community is not liable for any use that may be made of the information contained therein. Additional support from the Spanish Ministry of Education (AGL2007-29784-E/ALI; AP-2005-3827). Jara Valtueña is financially supported by the Universidad Politécnica de Madrid (CH/018/2008). Isabelle Sioen is financially supported by the Research Foundation—Flanders (grant no: 1.2.683.11.N.00).

Disclosure

The content of this article reflects only the author's view, and the rest of HELENA study members are not responsible for it. The writing group takes sole responsibility for the content of this article.

Conflict of interest: None declared.

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