Eur J Nutr (2015) 54:771–782
DOI 10.1007/s00394-014-0756-2

ORIGINAL CONTRIBUTION

Dietary fiber intake and its association with indicators of adiposity and serum biomarkers in European adolescents: the HELENA study

Yi Lin · Inge Huybrechts · Carine Vereecken · Theodora Mouratidou · Jara Valtueña · Mathilde Kersting · Marcela González-Gross · Selin Bolca · Julia Wärnberg · Magdalena Cuenca-García · Frederic Gottrand · Elisabetta Toti · Sonia Gomez-Martínez · Evangelia Grammatikaki · Idoia Labayen · Luis A. Moreno · Michael Sjöström · John Van Camp · Romana Roccaldo · Emma Patterson · Yannis Manios · Denes Molnar · Anthony Kafatos · Kurt Widhalm · Stefaan De Henauw

Received: 29 March 2014 / Accepted: 1 August 2014 / Published online: 17 August 2014

Abstract
Purpose To evaluate total, energy-adjusted dietary fiber (DF), water-soluble fiber (WSF), and water-insoluble fiber (WIF) intakes in European adolescents and to investigate their association with indicators of adiposity and serum biomarkers.
Methods This study, conducted from 2006 to 2007, included 1804 adolescents aged 12.5–17.5 years (47 % males) from eight European cities completing two non-consecutive computerized 24-h dietary recalls. GLM multivariate analysis was used to investigate associations.
Results Mean DF intake (20 g/day) of the sample met the European Food Safety Authority recommendation, but was below those of the World Health Organization and of the Institute of Medicine. Total DF, WSF and WIF intakes were higher in males ($P < 0.001$), but following energy-adjustments significantly higher intakes were observed among females ($P < 0.001$). Bread and cereals contributed most to total DF, WSF and WIF intakes, followed by potatoes and grains, energy-dense but low-nutritious foods, fruits and vegetables. Moreover, energy-adjusted WSF and WIF were positively associated with body fat percentage (BF%), waist to height ratio and low-density lipoprotein cholesterol, while energy-adjusted WSF was inversely associated with serum fasting glucose ($\beta = -0.\ 010$, $P = 0.020$).
Conclusion Total DF intakes are rather low in European adolescents. An inverse association with serum fasting

Y. Lin · I. Huybrechts (✉) · C. Vereecken · E. Grammatikaki · S. De Henauw
Department of Public Health, Faculty of Medicine and Health Sciences, Ghent University, UZ – 2 Blok A, De Pintelaan 185, 9000 Ghent, Belgium
e-mail: Inge.Huybrechts@UGent.be

I. Huybrechts
International Agency for Research on Cancer, Dietary Exposure Assessment Group, Lyon, France

C. Vereecken
Research Foundation – Flanders (FWO), Brussels, Belgium

T. Mouratidou · L. A. Moreno
Growth, Exercise, Nutrition and Development (GENUD) Research Group, Faculty of Health Sciences, University of Zaragoza, Domingo Miral s/n, 50009 Saragossa, Spain

J. Valtueña · M. González-Gross
ImFine Research Group, Department of Health and Human Performance, Faculty of Physical Activity and Sport Sciences (INEF), Universidad Politécnica de Madrid, 28040 Madrid, Spain

M. Kersting
Research Institute of Child Nutrition, Dortmund, Rheinische Friedich-Wilhelms-Universität Bonn, Forschungsinstitut fur Kinderernahrung Heinstück 11, 44225 Dortmund, Germany

S. Bolca
Laboratory for Bioinformatics and Computational Genomics (Biobix), Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

J. Wärnberg · S. Gomez-Martínez
Immunonutrition Research Group, Department of Metabolism and Nutrition, Institute of Food Science, Technology and Nutrition (ICTAN), Spanish National Research Council (CSIC), 10 Antonio Novais Street, 28040 Madrid, Spain

M. Cuenca-García
Department of Medical Physiology, School of Medicine, Granada University, Avenida Madrid 12, 18012 Granada, Spain

F. Gottrand
Inserm U995, IFR114, Faculté de Médecine, Université Lille, Lille, France

glucose might indicate a possible beneficial role of DF in preventing insulin resistance and its concomitant diseases, even though DF intakes were positively associated with adolescents' BF%. Therefore, further longitudinal studies should elaborate on these potential beneficial effects of DF intake in the prevention of obesity and related chronic diseases.

Keywords Dietary fiber · Adolescence · Adiposity · Biomarkers · HELENA study

Introduction

Evidence indicates that overweight (OW) and obesity (OB) during childhood is turning into the biggest epidemic concern of the twenty-first century [1]. Childhood OB is an important predictor of OB in adulthood [2]. In addition, its negative health consequences, i.e., metabolic syndrome, cardiovascular diseases, type 2 diabetes mellitus (T2DM), were reported to have a negative effect on life quality and result in higher prevalence of morbidity and mortality in adulthood [3–6]. In Europe, approximately 14 % of the children and adolescents participating in the KIDSCREEN Health Interview Survey were classified as OW, 51 % of those diagnosed with OW were adolescents [7]. Moreover, over 20,000 obese European children have been diagnosed with T2DM and over 400,000 with impaired glucose tolerance [4].

Dietary fiber (DF) classified into water-soluble fiber (WSF) and water-insoluble fiber (WIF), has been considered a leading dietary factor in the prevention and treatment of OB and its concomitant chronic diseases over the past four decades [8]. DF, as the residue of plant food resistant to hydrolysis by human alimentary enzymes, is a heterogeneous mixture of polysaccharides and lignin, offering potential health benefits to humans [9]. WSF delays small bowel absorption, which can subsequently reduce cholesterol absorption due to viscous solutions in the gastrointestinal tract [10]. In addition, fermentation of WSF can produce gases and short-chain fatty acids causing longer lasting satiety, lowering the glycemic index of foods and retarded absorption due to viscosity effects, consequently, slowing down acute insulin response [10, 11]. WIF, on the other hand, can increase the bulkiness of stool and fecal mass, thereby shortening the transit time due to non-digestibility [10].

A significant reduction of DF intake has been observed in industrialized countries paralleling with a dramatic rise of OB [12]. The World Health Organization (WHO) recommends an intake of 20 g/day of non-starch polysaccharides (NSP) and at least 25 g/day of total DF, which can protect against OB and its consequences [9]. The results of previous studies indicate that European adolescents had lower DF intake compared with the WHO recommendation, mainly due to high intakes from animal sources [13–18]. Evidence states that DF intake plays a strong role in the prevention of OW and OB in childhood [19–22] through weight maintenance and blood lipid regulation as a result of a balanced energy intake [10, 23]. Recent US longitudinal studies show that a high consumption of DF was beneficially affecting body composition in children [21, 24] and C-reactive protein (CRP) levels [25]. In a dietary intervention in OW

E. Toti · R. Roccaldo
Food and Nutrition Research Centre, Agricultural Research Council (CRA-NUT), Rome, Italy

E. Grammatikaki · Y. Manios
Department of Nutrition and Dietetics, Harokopio University, 70, El Venizelou Ave, 17671 Kallithea, Athens, Greece

I. Labayen
Department of Nutrition and Food Science, University of the Basque Country, Paseo de la Universidad, Biscay, Spain

M. Sjöström
Unit for Preventive Nutrition, Department of Biosciences and Nutrition, Karolinska Institute, 14183 Stockholm, Sweden

J. Van Camp
Department of Food Safety and Food Quality, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

E. Patterson
Samhällsnutrition och fysisk aktivitet, Karolinska Institutet, Centrum för epidemiologi och samhällsmedicin, 17129 Stockholm, Sweden

D. Molnar
Department of Pediatrics, University of Pécs, József A. u. 7, Pécs 7623, Hungary

A. Kafatos
Preventive Medicine and Nutrition Unit, School of Medicine, University of Crete, Heraklion, Crete, Greece

K. Widhalm
Department of Pediatrics, Private Medical University, Strubergasse 21, 5020 Salzburg, Austria

or OB adults, great improvements in risk factors of serum biomarkers including fasting lipids, glucose and insulin concentrations were observed in those participants with higher DF intake [26].

Because of lack of comprehensive knowledge of DF, WSF and WIF intakes, and food sources of DF in European adolescents, the purpose of the present study was to assess total, energy-adjusted DF, WSF and WIF intakes in European adolescents participating in the Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study (HELENA-CSS). Associations between energy-adjusted DF, WSF, WIF intakes and adiposity-related indicators [body mass index (BMI) *z*-score, body fat percentage (BF%), waist to hip ratio (WHR), waist to height ratio (*W*/*H*)] and serum biomarkers [total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), very low-density lipoprotein cholesterol (VLDL-C), high-density lipoprotein cholesterol (HDL-C), CRP, glucose, insulin and leptin] were examined.

Methods

Survey population

HELENA-CSS is a European Commission funded project on lifestyle and nutrition among adolescents from 10 European cities: Athens and Heraklion (Greece), Dortmund (Germany), Ghent (Belgium), Lille (France), Pecs (Hungary). Rome (Italy), Stockholm (Sweden), Vienna (Austria), and Zaragoza (Spain), that ran between October 2006 and December 2007. Due to logistical reasons, adolescents from Heraklion and Pecs were excluded from the dietary intake analyses. Male and female adolescents, aged 12.5–17.5 years [divided into the younger age group (12.5–14.9 years) and older age group (15.0–17.5 years)], not participating simultaneously in a clinical trial, and free of any acute infection lasting <1 week before inclusion year were recruited.

A multi-stage random cluster sampling procedure was used to select 3,528 adolescents, stratified by geographical location, age and socioeconomic status (SES). Schools were randomly selected after stratification to guarantee diversity of the sample in culture and SES. Details on sampling procedures, study design and non-respondents have been reported elsewhere [27–29]. Participants were included in this study if they had provided complete weight and height measurements and dietary assessment data. The study was approved by the Research Ethics Committees of each city involved. Written informed consent was obtained from the adolescents' parents and the adolescents themselves [30].

Dietary intake assessment

Two non-consecutive computerized 24-h dietary recalls, instructed by dieticians/researchers, were used to collect the food consumption data. During interviews, adolescents were allowed to ask questions and assistance, and after completion the recall was checked for completeness. Every participant was asked to fill in the HELENA-Dietary Assessments Tool (DIAT) twice in a time span of 2 weeks.

HELENA-DIAT is a self-administered computer program based on the Young Adolescents' Nutrition Assessment on Computer (YANA-C) [31], consisting of a single computerized 24-h dietary recall with a structured program based on six meal occasions (breakfast, mid-morning snack, midday meal, afternoon snack, evening meal and evening snack). The validated YANA-C was designed to obtain a detailed description and quantification of foods consumed, and eventually included about 800 food items hierarchically organized in 25 food groups, and about 300 colored photograph sets of foods in different portions [32, 33]. The 25 original food groups were aggregated into 11 summative ones: (1) beverages (including juices, excluding the rest group); (2) bread and breakfast cereals; (3) potatoes and grains; (4) total vegetables; (5) legumes, soy products, soy drinks; (6) total fruits; (7) milk, milk products, cheese (8) fat, oil, cream cheese, sour cream; (9) meat, poultry, fish, eggs, nut and seeds; (10) rest group defined as energy-dense, low-nutritious foods; (11) miscellaneous.

Dietary data of the HELENA-DIAT were linked to the dietary energy (kcal/day) and DF food composition data (g/day) of the German Food Code and Nutrient Data Base (BLS (Bundeslebensmittelschlüssel), version II.3.1, 2005) [34]. DF was defined as sum of all cellulotic polysaccharides, non-cellulotic polysaccharides and lignin. WSF (g/day) was the sum of total pectins, while WIF (g/day) was the sum of cellulose, lignin and hemi-cellulotic polysaccharides. Energy-adjusted DF intake (g/1,000 kcal/day) was also calculated using the energy density method [35]. In the present study, under-reporters, defined as individuals with a ratio of energy intake over estimated basal metabolic rate lower than 0.96 [36] were excluded from the study sample for the final data analyses.

Anthropometric measurements

Weight (kg), height (m), waist circumference (WC) (cm) and hip circumference (HC) (cm) were measured by well-trained researchers on underwear and barefoot adolescents. Weight was measured with an electronic scale (Type SECA 861. UK) to the nearest 0.1 kg and height in the Frankfort plane with a telescopic height measuring instrument (Type SECA 225, UK) to the nearest 0.1 cm. Thereafter, BMI (kg/m^2) and BMI *z*-score were calculated.

Participants were classified into four BMI categories according to the International Obesity Task Force (IOTF) criteria [37] as follows: underweight (UW) (<18.5 kg/m^2), normal weight (NW) (18.5–24.9 kg/m^2), OW (25.0–29.9 kg/m^2), and OB (≥30.0 kg/m^2), which was calculated based on the adjustment of gender and age. Skinfold thickness was measured to the nearest 0.2 mm in triplicate in the left side at biceps, triceps, subscapular, suprailiac, thigh and medial calf with a Holtain Caliper. BF% was calculated from skinfolds thicknesses (triceps and subscapular) using Slaughter's equations [38]. Waist and hip were measured in triplicate with an anthropometric un-elastic tape SECA 200 to the nearest 0.1 cm and thereafter WHR and *W/H* were calculated. BMI, BMI *z*-score and BF% were used as surrogates of total body fat and WHR and *W/H* as surrogates of central body fat. Identification of physical maturation (stages I–V) was assessed by a medical doctor according to Tanner and Whitehouse [39]. More details about the anthropometric measurements are given in a previous manuscript [40].

Blood sample

Blood samples were collected in a subsample of the total HELENA-CSS. Adolescents involved in the blood sampling were asked to fast after 8 pm on the previous day. In addition, a blood sampling questionnaire was completed by the participants for the purposes of assessing fasting status, acute infection, allergies, smoking, vitamin and mineral supplements, and medication.

A specific handling transport and traceability system for biological samples was developed for the HELENA study. Serum leptin (ng/mL) was measured using the RayBio Human Leptin ELISA (RayBiotech, Norcross, Georgia, USA) kit at UPM (Madrid). All samples were analyzed centrally. The blood sampling procedure has been described elsewhere [41].

Statistical analysis

Descriptive data are presented as mean with standard deviation (SD), median or frequency distributions stratified by gender and/or age group. Mean dietary intakes were corrected for within-person variation by means of the multiple source method (MSM) [42]. The normality of the data and equality of the variances were tested using the Kolmogorov–Smirnov and Levene's test, respectively. The statistical differences of anthropometry, serum biomarkers, total, energy-adjusted DF, WSF and WIS intakes between subgroups (gender and age) were checked by Student's *t* test, median test of nonparametric test, multiple analyses of covariance (MANCOVA). Results were considered statistically significant at a two-tailed level of 0.05.

GLM multivariate analysis was used to investigate the associations of total and central adiposity indicators (dependent variables) with energy-adjusted DF, WSF and WIF intakes (independent variables), controlling for center clustering effect. The categories of maternal and paternal educational level (lower and lower secondary education, higher secondary education and higher education or university degree; for both maternal and paternal education), physical activity level (at least 1 h physical activity each day, no physical activity or <1 h physical activity each day) and potential confounding factors, including age, gender and tanner stage (pre-puberty, puberty and post-puberty) and two-way interactions were included in the model. Two-way interactions were analyzed between potential confounding factors and independent variables. Indicators of total and central adiposity and serum biomarkers were investigated separately. Serum biomarkers were put in the model after log transformation. The predicted clinical values of biomarkers based on increasing 1 g intakes of energy-adjusted total DF/WSF/WIF have been reported after back log transformation. In addition, energy-adjusted total, WSF and WIF intakes were examined in a separate model due to collinearity.

All statistical analysis was performed using SPSS for Windows version 18.0 (SPSS Inc., Chicago, IL, USA).

Results

A total of 1,804 out of 3,528 adolescents (47 % males) from eight centers with completed, valid dietary information on 2 independent days, were included in the final analysis (Table 1). Only nine males were classified in Tanner stage 1, with 25 % of total sample in Tanner stage 5. In total, 279 adolescents were classified as OW and OB (12 and 3 %, respectively). Females had higher BF%, serum lipid values and leptin concentrations than males, but lower BMI *z*-score, WC and WHR compared to males (Table 1). Furthermore, female adolescents had higher serum lipid profiles and leptin concentrations than males.

Total energy and dietary fiber intake

Total energy intake among European adolescents was 2,450 kcal/day (range 1,053–5,472 kcal/day). Mean total DF intake was 20 g/day (range 8.4–84 g/day), and mean energy-adjusted DF intake was 8.4 g/1,000 kcal (3.3–21 g/1,000 kcal/day). Additionally, mean WSF and WIF intakes were 6.5 g/day (2.8–34 g/day) and 14.5 g/day (5.7–49 g/day), respectively (Table 2). Males had significantly higher intake of energy, DF, WSF and WIF ($P < 0.001$ for all), but lower energy-adjusted DF intakes than females ($P < 0.001$). Older adolescents had significantly higher

Table 1 Anthropometric characteristics and serum biomarkers of adolescents participating in the HELENA-CSS

Items	Total (n = 1,804)		Males (n = 855)		Females (n = 949)	
Tanner stage (n = 1,752)	%					
Tanner 1	0.514		1.1		0.000	
Tanner 2–4	73.9		74.2		73.5	
Tanner 5	25.6		24.7		26.5	
BMI category (n = 1,804)						
Underweight	7.9		6.8		8.9	
Normal weight	76.7		75.9		77.3	
Overweight	12.3		13.3		11.4	
Obesity	3.2		4.0		2.4	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	14.7	1.2	14.8	1.3	14.7	1.2
Anthropometry (n = 1,804)[a]						
BMI z-score	0.270	1.1	0.358	1.1	0.190*	1.0
BF%	22.0	8.6	18.4	9.1	25.1*	6.8
WC (cm)	71.0	7.9	72.7	8.3	69.5*	7.1
WHR	0.626	0.084	0.664	0.088	0.591*	0.061
W/H	0.429	0.045	0.429	0.046	0.429	0.045
Serum biomarkers[a]	Median		Median		Median	
TC (mg/dL) (n = 552)	158.0		151.0		166.0*	
TG (mg/dL) (n = 552)	60.0		58.0		61.0	
LDL-C (mg/dL) (n = 552)	92.0		89.0		94.0**	
VLDL-C (mg/dL) (n = 552)	12.0		11.6		12.2	
HDL-C (mg/dL) (n = 552)	55.0		52.0		57.0*	
CRP (mg/L) (n = 524)	0.682		0.671		0.692	
Glucose (mg/dL) (n = 552)	90.0		91.0		88.0*	
Insulin (μL U/mL) (n = 545)	8.2		7.8		8.6**	
Leptin (ng/mL) (n = 518)	10.0		3.6		18.7*	

SD standard deviation, *BMI* body mass index, *BF%* body fat percentage, *WC* waist circumference, *WHR* waist to hip ratio, *W/R* waist to height ratio, *TC* total cholesterol, *TG* triglycerides, *LDL* low-density lipoprotein cholesterol, *VLDL-C* very low-density lipoprotein cholesterol, *HDL-C* high-density lipoprotein cholesterol, *CRP* c-reactive protein

* Mean/median value was significantly different between genders, $P \leq 0.001$, Student's t test

** Mean/median value was significantly different between genders, $P < 0.05$, Student's t test

[a] Statistical difference was used Student's t test for mean value of anthropometry and median test of nonparametric test for serum biomarkers

intakes of DF, WSF and WIF than their younger peers (Ps ≤ 0.003).

Furthermore, OW and obese females consumed less mean total and energy-adjusted DF intakes compared to UW and NW peers (Fig. 1). No significant differences were observed in total and energy-adjusted DF intakes among BMI categories in males and in the age groups.

Total and energy-adjusted DF intakes were compared to international guidelines (Table 3). Mean DF intake was on average 20 g/day, which is below the recommendation of WHO [18] and of Institute of Medicine (IOM) [43] with only 20 and 2.5 % of the participants meeting the recommendations, respectively. Whereas approximately 80 % of the adolescents met the recommendations proposed by the European Food Safety Authority (EFSA), only 7.5 % exceeded 30 g/day (103 males and 33 females) [44]. Concerning energy-adjusted DF intake (8.4 g/1,000 kcal/day), 74 % adolescents were in line with the EFSA recommendation [44]. In general, fewer OW and obese adolescents met the total DF intake requirements of WHO, EFSA and IOM, compared to the UW and NW peers.

Food groups contributing to total, water-soluble and water-insoluble dietary fiber intakes

The main food groups contributing to total DF, WSF and WIF intakes in the total population, and among males and females consisted of bread and cereals (bread and rolls in particular), followed by potatoes and grains, rest group products, fruits and vegetables (Table 4). The main contributing food subgroups were the fruit subgroup including fresh fruits, fruit salad and processed fruit, the vegetable subgroup including fresh vegetables, vegetable salad, prepared vegetables excluding potatoes, and the potatoes and grains subgroup including starch roots, potatoes contributing more among females; while among males, bread and rolls, pasta, breakfast cereals, rice and other cereals contributed relatively more.

Adiposity indicators and serum biomarkers

Further investigation shows that, on the one hand, BF% was positively associated with energy-adjusted WSF and WIF intakes ($\beta = 1.7$, $P = 0.005$; $\beta = 0.706$, $P = 0.014$, respectively), and *W/H* and LDL-C positively with energy-adjusted WSF intakes ($\beta = 0.009$, $P = 0.014$; $\beta = 0.031$, $P = 0.047$); on the other hand, serum fasting glucose was inversely associated with energy-adjusted WSF intake, respectively ($\beta = -0.010$, $P = 0.020$). With increasing 1 g intakes of energy-adjusted WSF/WIF, BF% could increase by 1.7/0.706 %, respectively, *W/H* by 0.009 ratio unit and LDL-C by 0.031 mg/dL with 1.03 mg/dL predicated clinical value; while with 1 g energy-adjusted WSF intake, serum fasting glucose could reduce 0.010 mg/dL with 0.990 mg/dL predicated clinical value. Total energy-adjusted fiber intake was not associated with any adiposity and biomarker parameters (Table 5).

Table 2 Estimated mean total energy intake, and total, energy-adjusted, water-soluble and water-insoluble dietary fiber intakes of adolescents participating in the HELENA-CSS stratified by gender and age category ($n = 1{,}804$)

Intakes[a]	Total		Males		Females		P*	12.5–14.9 years		15.0–17.5 years		P**
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Energy (kcal/day)	2,449.6	636.6	2,792.2	655.1	2,140.9	427.8	<0.001	2,358.4	572.8	2,571.5	695.0	<0.001
Total fiber (g/day)	20.3	6.4	21.7	6.8	19.0	5.8	<0.001	19.7	6.4	21.0	6.4	0.002
Energy-adjusted fiber (g/1,000 kcal/day)	8.4	2.0	7.8	1.7	8.9	2.1	<0.001	8.4	2.0	8.3	2.0	0.074
Water-soluble dietary fiber (g/day)	6.5	2.1	7.0	2.1	6.1	1.9	<0.001	6.4	2.1	6.8	2.0	0.001
Water-insoluble dietary fiber (g/day)	14.5	4.6	15.6	5.0	13.6	4.1	<0.001	14.1	4.5	15.0	4.7	0.003

SD standard deviation

* Mean value was significantly different between genders

** Mean value was significantly different between age categories

[a] Multiple analyses of covariance (MANCOVA) ($P < 0.05$, Bonferroni)

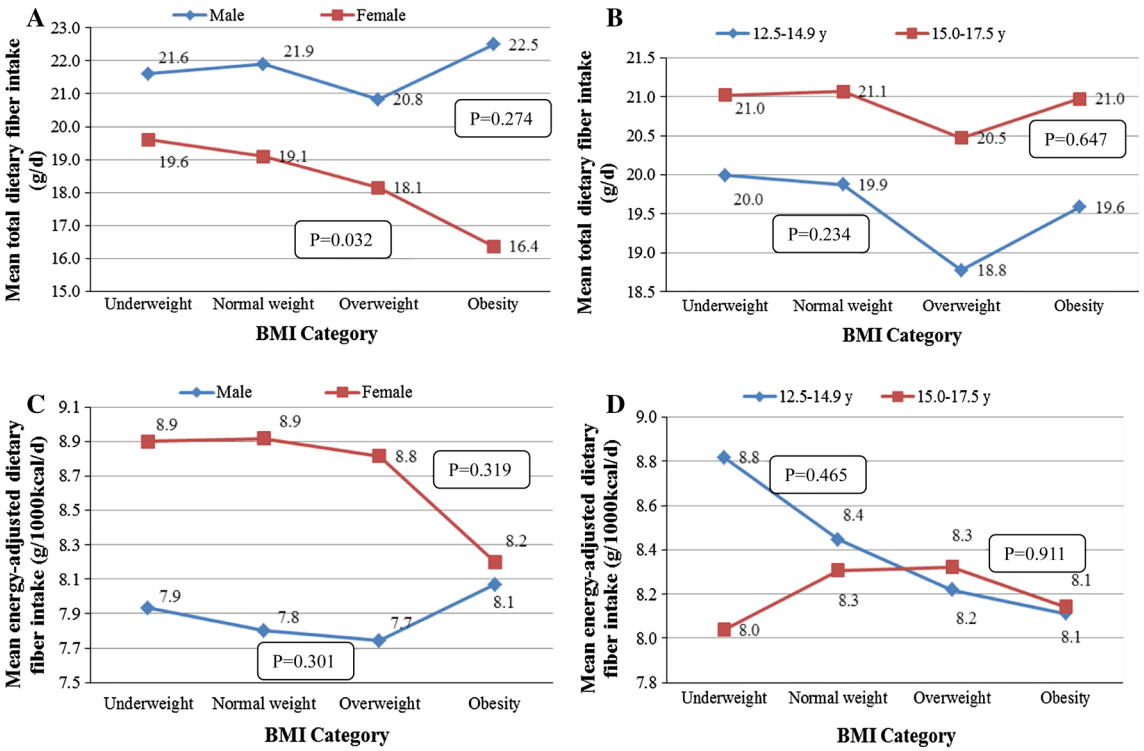

Fig. 1 Mean (**a**, **b**) total and (**c**, **d**) energy-adjusted dietary fiber intakes by BMI category stratified by gender (**a**, **c**) and age (**b**, **d**) of adolescents participating in the HELENA-CSS

Discussion

Dietary fiber intakes

This is the first large European adolescent population-based dietary survey to provide data about total DF, energy-adjusted DF, WSF and WIF intakes among European adolescents. Total DF intake in the study was below the WHO and IOM recommendations, but met the EFSA criteria. Rolland-Cachera et al. [16] suggested insufficient DF intakes in adolescents from Western Europe, which is in line with recent research on DF intake in Belgian adolescents [15]. This could be attributed to the more westernized style of eating: our data suggest that European adolescents have higher consumption of animal sources and energy-dense, low-nutritious foods, and lower

Table 3 Proportion of adolescents participating in the HELENA-CSS meeting the international recommendations for total and energy-adjusted fiber intake ($n = 1{,}804$)

Organization	Recommendation	Intakes in line with the recommendation (%)						
		All	Males	Females	UW	NW	OW	OB
WHO	Total fiber: 25 g/day	20.0	27.8	14.5	19.0	20.8	15.3	22.8
EFSA	Total fiber: 15–30 g/day	80.0	84.8	83.9	84.5	79.5	77.5	78.9
EFSA	Energy-adjusted fiber: 7.1–10.5 g/1,000 kcal/day	73.6	62.8	93.2	75.4	73.0	75.7	77.2
IOM	Males total fiber: 38 g/day	NA	2.1	NA	1.7	1.8	2.6	5.9
IOM	Females total fiber: 26 g/day	NA	NA	11.4	11.9	11.0	5.6	0.0

WHO World Health Organization, *EFSA* European Food Safety Authority, *IOM* Institute of Medicine, *UW* underweight, *NW* normal weight, *OW* overweight, *OB* obesity, *NA* not available

consumption of vegetables and fruits. These findings are in accordance with the results reported from a study conducted in Southern Europe showing high levels of total and saturated fat intakes [13]. Similarly, OW and obese Swiss children and young adolescents consume more dairy and meat products, but much less vegetables compared with NW peers [45], a trend which was also observed in Spanish adolescents [46]. Total DF intake of the adolescents participating in HELENA was higher than in Belgian (male: 17.8 g/day; female: 15.0 g/day) and US (13.7 g/day) adolescents, due to lower vegetable and fruit intakes in both Belgian and US populations [15, 47]. The Asian dietary style is known to consume more foods derived from plant sources compared to the Western style. Additionally, higher energy-adjusted DF intakes were reported in our study than that of Japanese adolescents (12–15 years) (5.6 g/1,000 kcal/day for both NW and OW males; 5.8–6.0 g/1,000 kcal/day for NW and OW females) [48] and Chinese children aged 7–17 years old (NW: 5.4 g/1,000 kcal/day; OW: 5.0 g/1,000 kcal/day) [49]. The ratio of WIF and WSF intakes was lower in our study (2.2 for both genders) than in Japanese adolescents (3.7 for both genders), however, both mean WSF and WIF intakes were higher than those estimated in the whole Japanese population in 1998 (3.2 and 11.2 g/day, respectively) [12]. Different standards for food portion sizes due to different cultures and differences in food composition can result in the diversity, and as well as the ranking of contributors to the dietary intakes may be a possible factor. Additionally, observed variations might be attributed to differences in dietary assessment methodology, regional dietary habits, population characteristics and use of food composition tables and regional dietary habits.

In the present study, the most important contributors to DF, WSF and WIF intakes were bread and cereals, followed by rest group products, potatoes and grains, fruits and vegetable. Similar food groups were identified as the major contributors in Belgian (15–18 years) [15] and Italian (mean age: 17 years) adolescents [14] using two repeated, non-consecutive 24-h dietary recalls, and three times 4-consecutive-day 24-h dietary records, respectively. Considering the sub-contributors, legume was one of the main contributors in Italian [14] and US children (2–18 years, in-person 24-h dietary recall) [50], but not for European adolescents. Likewise, rice/wheat and vegetables were top two sub-contributors reported in the Chinese children [49]. Additionally, findings show that energy-dense, low-nutritious foods were consumed in higher amounts than healthy foods such as vegetables and fruits in adolescents.

Associations between dietary fiber intakes and indicators of body composition and serum biomarkers

DF has been used in the prevention or treatment of OB in children and adults [51]. According to our results, OW adolescents had lower total, energy-adjusted DF intakes than UW and NW participants, females in particular. Aeberli et al. [45] reported that total DF intake was significantly lower in Swiss OW boys, but not in girls. The tendency of total DF intake throughout the weight groups, except females, shows that OB adolescents had the highest consumption of DF. However, differential misreporting (e.g., more underreporting among the obese) could bias those results.

No associations were observed in the present study between body composition indicators and energy-adjusted total DF. Previous studies show an inverse association between DF intake and BMI in healthy female adolescents [24] and central adiposity in OW adolescents [21, 52]. However, some studies found no associations of high DF intakes with change of body weight and composition [53, 54]. Previous findings reported by Cheng et al. [54] stated that DF intake might not affect the development of BF% or BMI during puberty. Likewise, a non-significant change in BF% and BMI upon high consumption of whole-grain-derived DF in adolescents was described [54]. However,

Table 4 The contributions (%) of consumption of different food groups to total, water-soluble and water-insoluble dietary fiber intakes

Food groups[a]	Rank	Total fiber			Water-soluble dietary fiber			Water-insoluble dietary fiber		
		All	Males	Females	All	Males	Females	All	Males	Females
Beverages (including juices, excluding the rest group)		3.0	3.0	3.1	3.5	3.5	3.5	2.8	2.8	2.8
Bread and breakfast cereals		24.5	25.8	23.7	27.4	28.8	26.8	22.2	23.5	21.4
Bread and rolls	1	20.8	21.6	20.5	24.4	25.3	24.1	18.4	19.2	18.1
Breakfast cereals	8	3.7	4.2	3.3	3	3.4	2.7	3.7	4.3	3.3
Potatoes and grains		17.5	18.0	16.9	20.1	20.6	19.4	17.9	18.3	17.4
Starch roots, potatoes	6	6.7	6.4	7.0	6.9	6.5	7.2	7.1	6.8	7.4
Pasta	4	7.7	8.0	7.3	9.3	9.5	8.9	8.0	8.3	7.7
Total vegetables		10.0	9.0	11.0	9.6	8.8	10.3	10.2	9.0	11.2
Fresh vegetables, vegetable salad excluding potatoes	3	9.8	8.8	10.7	9.3	8.6	10.0	10.0	8.9	11.0
Legume, soy products, soy drinks		3.8	3.3	4.0	5.4	4.7	5.7	2.8	2.5	3.0
Pulses (excluding fresh peas, sweet corn and broad bean)	10	2.7	2.8	2.4	3.8	4.0	3.2	2.0	2.1	1.8
Total fruits		14.1	12.7	15.4	13.3	12.1	14.4	14.1	12.8	15.5
Fresh fruits, fruit salad, processed fruit	2	13.9	12.6	15.1	13.1	12.0	14.2	14.0	12.6	15.3
Milk, milk products, cheese		3.9	4.0	3.7	1.9	2.0	1.8	4.7	4.8	4.5
Fat, oil, cream cheese, sour cream		0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
Meat, poultry, fish, eggs, nut and seeds		4.5	4.5	4.5	5.2	5.1	5.2	4.2	4.2	4.2
Meat, poultry and processed meat	9	2.9	3.2	2.5	3.1	3.6	2.6	2.8	3.1	2.4
Rest group (snacks and desserts)[b]		16.7	17.4	16.2	11.5	11.9	11.2	19.1	19.9	18.6
Cakes, pies, biscuits	6	6.3	6.1	6.4	6.5	6.3	6.6	6.4	6.2	6.6
Chocolate	7	5.5	6.1	5.0	1.8	2.0	1.6	7.2	7.9	6.6
Miscellaneous		1.7	2.0	1.2	1.8	2.2	1.4	1.7	2.0	1.2

[a] Top 10 food subgroups contributed to most total fiber intake. The food groups and subgroups: (1) beverages (including juices, excluding the rest group) including subgroups of (a) water, (b) soups and bouillon, (c) coffee and tea, (d) fruit and vegetable juices, (e) carbonated/soft/isotonic drinks including non-alcoholic wine, non-alcoholic beer, (f) beer, (g) wine and cider, (h) other alcoholic beverages; (2) bread and breakfast cereals including subgroups of (a) bread and rolls, (b) breakfast cereals; (3) potatoes and grains including subgroups of (a) starch roots and potatoes, (b) pasta, (c) rice and other cereals, (d) flour; (4) total vegetables including subgroups of (a) fresh vegetables, vegetable salad, prepared vegetables excluding potatoes, (b) meat substitutes and vegetarian products; (5) legume, soy products, soy drinks including subgroups of (a) pulses (excluding fresh peas, sweet corn and broad bean), (b) soya beverages, (c) desserts and puddings soya based; (6) total fruits including subgroups of (a) fresh fruits, fruit salad, processed fruit, (b) olives and avocado; (7) milk, milk products, cheese including subgroups of (a) white milk and buttermilk, (b) yogurt and from age blanc (quark), (c) milk and yogurt beverages, (d) cheese [excluding from age blanc (quark)], (e) desserts and puddings milk based (including ice cream), (f) other milk products; (8) fat, oil, cream cheese, sour cream including subgroups of (a) butter and animal fats, (b) margarine and lipids of mixed origins; (9) meat, poultry, fish, eggs, nut and seeds including subgroups of (a) meat, poultry and processed meat, (b) fish products, (c) eggs, (d) nuts and seeds (including nut- and seed-spreads), (e) nuts, seeds and olives; (10) rest group including subgroups of (a) cakes, pies, biscuits, (b) savory snacks, (c) chocolate, (d) creams (including non-dairy and coffee creams), (e) sugar, honey, jam and syrup, (f) confectionery non chocolate, (g) other sugar products, (h) sauces (excluding dessert sauces), (i) products for special nutritional use; (11) miscellaneous

[b] Rest group (snacks and desserts) was defined as energy-dense, low-nutritious foods

positive associations of BF% and *W/H* were found with WSF and WIF. These results are in conflict with other studies indicating that a high consumption of WSF, including fruit- and vegetable-derived DF [25, 55, 56] and WIF, such as cereal-derived DF [22, 25, 57–59], not only benefits body composition, but also improves blood lipids, glucose and insulin sensitivity due to low-glycemic index diets. Serum fasting glucose concentration was inversely associated with energy-adjusted WSF intake in our study, which is in line with the above indications. However, LDL-C was found positively associated with energy-adjusted WSF intake, while evidence shows that increasing the consumption of DF may protect against high serum TC, TG, LDL-C and CRP concentrations, and improve glucose concentrations in adults [23, 25, 60]. Consistent with our findings, low DF intakes may be associated with insulin resistance among 8- to 10-year-old and 14- to 16-year-old Danish girls [61]. Conversely, one randomized clinical trial involving children, aged 5–17 years, with hypercholesterolemia showed that cereal- and water-soluble psyllium-

Table 5 Associations between indicators of adiposity and serum biomarkers, and energy-adjusted total, water-soluble and water-insoluble dietary fiber intakes of adolescents participating in the HELENA-CSS

Dependent variables	Energy-adjusted total dietary fiber[a]					
	β	SE	95 % CI		The predicted clinical value[c] (95 % CI)	*P*
Body composition						
BMI *z*-score	0.024	0.031	−0.037	0.086	0.024 (−0.037 to 0.086)	0.436
BF%	0.355	0.233	−0.102	0.812	0.355 (−0.102 to 0.812)	0.127
WHR	0.000	0.002	−0.004	0.005	No change	0.824
W/H	0.001	0.001	−0.002	0.003	0.001 (−0.002 to 0.003)	0.598
Serum biomarkers[b]						
TC	0.001	0.002	−0.003	0.005	1.00 (0.997–1.01)	0.669
TG	0.004	0.006	−0.008	0.015	1.00 (0.992–1.02)	0.531
LDL-C	0.006	0.004	−0.001	0.013	1.01 (0.999–1.01)	0.101
VLDL-C	0.004	0.006	−0.008	0.015	1.00 (0.992–1.02)	0.531
HDL-C	−0.002	0.003	−0.007	0.003	0.998 (0.993–1.00)	0.397
CRP	−0.016	0.017	−0.050	0.018	0.016 (−0.049 to 0.018)	0.347
Glucose	0.000	0.001	−0.002	0.002	1.00 (0.998–1.00)	0.687
Insulin	−0.014	0.007	−0.028	0.000	0.986 (0.972–1.00)	0.056
Leptin	−0.012	0.013	−0.037	0.014	0.988 (0.964–1.01)	0.375
	Energy-adjusted water-soluble dietary fiber[a]					
BMI *z*-score	0.157	0.082	−0.004	0.319	0.157 (−0.004 to 0.319)	0.055
BF %	1.7	0.608	0.508	2.9	1.7 (0.508–2.9)	0.005
WHR	0.003	0.006	−0.008	0.014	0.003 (−0.008 to 0.014)	0.543
W/H	0.009	0.003	0.002	0.015	0.009 (0.002–0.015)	0.014
Serum biomarkers[b]						
TC	0.010	0.010	−0.009	0.029	1.01 (0.991–1.03)	0.291
TG	0.040	0.025	−0.009	0.089	1.04 (0.991–1.09)	0.106
LDL-C	0.031	0.016	0.000	0.062	1.03 (1.00–1.06)	0.047
VLDL-C	0.040	0.025	−0.009	0.089	1.04 (0.991–1.09)	0.106
HDL-C	−0.008	0.011	−0.029	0.014	0.992 (0.971–1.01)	0.479
CRP	−0.021	0.074	−0.167	0.124	0.021 (−0.154 to 0.132)	0.772
Glucose	−0.010	0.004	−0.018	0.002	0.990 (0.982–1.00)	0.020
Insulin	−0.017	0.031	−0.078	0.044	0.983 (0.925–1.04)	0.577
Leptin	−0.036	0.055	−0.145	0.073	0.965 (0.865–1.08)	0.513
	Energy-adjusted water-insoluble dietary fiber[a]					
Body composition						
BMI *z*-score	0.054	0.039	−0.022	0.129	0.054 (−0.022 to 0.129)	0.165
BF%	0.706	0.287	0.143	1.3	0.706 (0.143–1.3)	0.014
WHR	0.000	0.003	−0.005	0.005	No change	0.971
W/H	0.002	0.002	−0.007	0.002	0.002 (−0.007 to 0.002)	0.316
Serum biomarkers[b]						
TC	0.001	0.003	−0.005	0.006	1.00 (0.995–1.01)	0.804
TG	0.006	0.007	−0.009	0.021	1.01 (0.991–1.02)	0.431
LDL-C	0.007	0.005	−0.002	0.017	1.01 (0.998–1.02)	0.118
VLDL-C	0.006	0.007	−0.009	0.021	1.01 (0.991–1.02)	0.431
HDL-C	−0.004	0.003	−0.010	0.003	0.996 (0.990–1.00)	0.251
CRP	−0.014	0.022	−0.058	0.029	0.014 (−0.056 to 0.029)	0.519
Glucose	−0.001	0.001	−0.004	0.001	0.999 (0.996–1.00)	0.410
Insulin	−0.015	0.009	−0.033	0.003	0.985 (0.968–1.00)	0.105
Leptin	−0.012	0.016	−0.045	0.020	0.988 (0.956–1.02)	0.455

SE standard error of coefficient *β*, *CI* confidence interval

[a] In the model, analysis was controlled for country clustering, the categories of maternal and paternal education level (lower and lower secondary education, higher secondary education and higher education or university degree for both maternal and paternal education), physical activity level (at least 1 h physical activity each day, no physical activity or <1 h physical activity each day) and potential confounding factors including age, gender and tanner stage, and two-way interactions between potential confounding factors and energy-adjusted water-soluble/water-insoluble dietary fiber (separate model)

[b] Serum biomarkers were included in the model after log transformation

[c] The predicted clinical values of biomarkers were calculated after back log transformation based on increasing 1 g intakes of energy-adjusted total dietary fiber/water-soluble dietary fiber/water-insoluble dietary fiber

derived DF intakes did not improve blood lipid profiles [62], unlike the results of Anderson et al. [63] in hypercholesterolemic ambulatory adults. A review study concluded that fruit- and vegetable-derived DF intakes do not directly reduce the risk of OW and OB, whereas WIF does directly reduce the risk of OW and OB [64]. Although total DF, WSF and WIF intake did not have strong associations with body composition and biomarkers, high DF consumption during adolescence was suggested to result in adjustment of blood lipid profile, improvement of insulin resistance and lower systolic blood pressure during young adulthood [65].

It is noteworthy that physical activity was a very critical confounder as the relationship of DF intakes with adiposity indicators and serum biomarkers was modified after adjusting for physical activity levels (data not shown). Potential confounding factors, such as Tanner stage and region, may explain the effect of DF intake on the contradictory outcome measurements. The small sample size for blood sample collections involved in the current study may also be a potential influencing factor. Although statistical analyses in the current study were adjusted for the Tanner stage, center, age, gender and physical activity, it is likely that the observed weak linear relationship of serum biomarkers with DF intakes may be caused by minor variation of misreporting. Puberty in particular may bias the effect of DF intake on OB-related parameters [24, 53, 54].

Strengths and limitations

HELENA CSS is the first large-scale survey assessing nutrition related aspects among European adolescents, via standardized procedures. Furthermore, it is the first study evaluating total and energy-adjusted DF, WSF and WIF intakes in European adolescents, in relation to adiposity-related indicators, including adiposity and serum biomarkers. Standardized procedures were used to estimate the adolescent's dietary intakes by means of duplicate computer-assisted 24-h dietary recalls. Also all other lifestyle indicators and biomarkers were collected via standardized procedures.

Nonetheless, some limitations of this study need to be considered. A first limitation of the method used is, however, that only information of 2 days was collected. The 24-h dietary recall method does not allow accurate assessments of infrequently consumed foods. In order to correct for such errors, nutrient intakes were corrected for within-person variability by applying the MSM method. Moreover, accuracy of collected data relies on the individual's memory in the past 24 h and might, therefore, be biased toward underreporting. In this respect, the 24-h dietary recalls were performed through computer-assisted HELENA-DIAT software to standardize the recall procedures as much as possible.

Since DF definitions differ between the different local food composition tables and due to many missing data of fiber content in these tables, the same food composition table for conversion of food intake data to estimated nutrient intakes was used for all survey centers. In this way, differences in definitions, analytical methods, units and modes of expression were overcome. In this regard, the dietary data of the HELENA-DIAT were linked to BLS [34]. Data from each country were linked to this database to ensure standardization of available measures. However, DF contents of missing foods in the BLS table were calculated via recipes or borrowed from local food composition tables. Second, the small sample size of serum biomarkers could result in weak linear relationships between DF intakes and serum biomarkers. Additionally, we did not consider food processing, which may have influenced the accuracy of total, WSF and WIF estimates.

Conclusion

In this first large-scale nutrition survey among European adolescents, average total and energy-adjusted DF intakes met the EFSA recommendations, but were below the WHO and IOM recommendations. The food group of bread and cereals was the most important contributor to total DF, WSF and WIF intakes, followed by rest group products, potatoes and grains, fruits and vegetables. Furthermore, our results indicate that energy-adjusted WSF and WIF are positively related to BF%, *W/H* and LDL-C, but inversely related to serum glucose. Although few associations were found, WSF and WIF may play a beneficial role in DF by preventing insulin resistance and its concomitant diseases, due to low-glycemic index diets. However, DF intakes can be positively related to adolescents' BF%. Further longitudinal studies should carry on these potential effects of DF intake in the prevention of OB and/or related chronic diseases.

Acknowledgments The HELENA-study took place with the financial support of the European Community Sixth RTD Framework Programme. This work was also partially supported by the European Union, in the framework of the Public Health Programme, the Swedish Council for Working Life and Social Research, the Spanish Ministry of Education, Spanish Ministry of Science and Innovation (AGL2007-29784-E) and the Spanish Ministry of Health, Maternal, Child Health and Development Network. The content of this paper reflects only the authors' views and the rest of HELENA-study members and the European Community is not liable for any use that may be made of the information contained therein. Yi Lin was responsible for the analyses and the drafting of the manuscript. Many thanks to Petra Pickert, Anke Carstensen, Rosa María Torres for their contribution to laboratory work. All authors contributed to the interpretation of the results and have evaluated and approved the manuscript as submitted.

Conflict of interest The authors declare that there are no conflicts of interests.

References

1. Baur LA (2002) Child and adolescent obesity in the 21st century: an Australian perspective. Asia Pac J Clin Nutr 11(Suppl. 3):S524–S528
2. Engeland A, Bjorge T, Sogaard AJ, Tverdal A (2003) Body mass index in adolescence in relation to total mortality: 32-year follow-up of 227,000 Norwegian boys and girls. Am J Epidemiol 157:517–523
3. Lloyd LJ, Langley-Evans SC, McMullen S (2010) Childhood obesity and adult cardiovascular disease risk: a systematic review. Int J Obes (Lond) 34:18–28
4. Lobstein T, Jackson-Leach R (2006) Estimated burden of paediatric obesity and co-morbidities in Europe. Part 2. Numbers of children with indicators of obesity-related disease. Int J Pediatr Obes 1:33–41
5. Ogden CL, Flegal KM, Carroll MD, Johnson CL (2002) Prevalence and trends in overweight among US children and adolescents, 1999–2000. JAMA 288:1728–1732
6. Power C, Lake JK, Cole TJ (1997) Measurement and long-term health risks of child and adolescent fatness. Int J Obes Relat Metab Disord 21:507–526
7. Ottova V, Erhart M, Rajmil L, Dettenborn-Betz L, Ravens-Sieberer U (2012) Overweight and its impact on the health-related quality of life in children and adolescents: results from the European KIDSCREEN survey. Qual Life Res 21(1):59–69
8. Anderson JW, Smith BM, Gustafson NJ (1994) Health benefits and practical aspects of high-fiber diets. Am J Clin Nutr 59:1242S–1247S
9. Joint FAO/WHO expert consultation on diet NatPoCD (2003) Diet, nutrition, and the prevention of chronic diseases. WHO technical report series 91634-63
10. Tan KY, Seow-Choen F (2007) Fiber and colorectal diseases: separating fact from fiction. World J Gastroenterol 13:4161–4167
11. Mathern JR, Raatz SK, Thomas W, Slavin JL (2009) Effect of fenugreek fiber on satiety, blood glucose and insulin response and energy intake in obese subjects. Phytother Res 23:1543–1548
12. Nakaji S, Sugawara K, Saito D, Yoshioka Y, MacAuley D, Bradley T et al (2002) Trends in dietary fiber intake in Japan over the last century. Eur J Nutr 41:222–227
13. Cruz JA (2000) Dietary habits and nutritional status in adolescents over Europe-Southern Europe. Eur J Clin Nutr 54(Suppl. 1):S29–S35
14. Leclercq C, Piccinelli R, Arcella D, Le Donne C (2004) Food consumption and nutrient intake in a sample of Italian secondary school students: results from the INRAN-RM-2001 food survey. Int J Food Sci Nutr 55:265–277
15. Lin Y, Huybrechts I, Vandevijvere S, Bolca S, De Keyzer W, De Vriese S et al (2011) Fibre intake among the Belgian population by sex-age and sex-education groups and its association with BMI and waist circumference. Br J Nutr 105:1692–1703
16. Rolland-Cachera MF, Bellisle F, Deheeger M (2000) Nutritional status and food intake in adolescents living in Western Europe. Eur J Clin Nutr 54(Suppl. 1):S41–S46
17. Serra-Majem L, Ribas-Barba L, Salvador G, Jover L, Raido B, Ngo J et al (2007) Trends in energy and nutrient intake and risk of inadequate intakes in Catalonia, Spain (1992–2003). Public Health Nutr 10:1354–1367
18. WHO (2009) Population nutrient intake goals for preventing diet-related chronic diseases. http://www.who.int/dietphysicalactivity/publications/trs916/en/gsfao_overall.pdf. (Accessed 18 Dec 2011)
19. Albertson AM, Affenito SG, Bauserman R, Holschuh NM, Eldridge AL, Barton BA (2009) The relationship of ready-to-eat cereal consumption to nutrient intake, blood lipids, and body mass index of children as they age through adolescence. J Am Diet Assoc 109:1557–1565
20. Buyken AE, Cheng G, Gunther AL, Liese AD, Remer T, Karaolis-Danckert N (2008) Relation of dietary glycemic index, glycemic load, added sugar intake, or fiber intake to the development of body composition between ages 2 and 7 y. Am J Clin Nutr 88:755–762
21. Davis JN, Alexander KE, Ventura EE, Toledo-Corral CM, Goran MI (2009) Inverse relation between dietary fiber intake and visceral adiposity in overweight Latino youth. Am J Clin Nutr 90:1160–1166
22. Rampersaud GC, Pereira MA, Girard BL, Adams J, Metzl JD (2005) Breakfast habits, nutritional status, body weight, and academic performance in children and adolescents. J Am Diet Assoc 105:743–760
23. Hodgson JM, Lee YP, Puddey IB, Sipsas S, Ackland TR, Beilin LJ et al (2010) Effects of increasing dietary protein and fibre intake with lupin on body weight and composition and blood lipids in overweight men and women. Int J Obes (Lond) 34:1086–1094
24. Affenito SG, Thompson DR, Barton BA, Franko DL, Daniels SR, Obarzanek E et al (2005) Breakfast consumption by African-American and white adolescent girls correlates positively with calcium and fiber intake and negatively with body mass index. J Am Diet Assoc 105:938–945
25. Ma Y, Griffith JA, Chasan-Taber L, Olendzki BC, Jackson E, Stanek EJIII et al (2006) Association between dietary fiber and serum C-reactive protein. Am J Clin Nutr 83:760–766
26. Pal S, Khossousi A, Binns C, Dhaliwal S, Ellis V (2011) The effect of a fibre supplement compared to a healthy diet on body composition, lipids, glucose, insulin and other metabolic syndrome risk factors in overweight and obese individuals. Br J Nutr 105:90–100
27. Beghin L, Huybrechts I, Vicente-Rodriguez G, De Henauw S, Gottrand F, Gonzalez-Gross M et al (2012) Mains characteristics and participation rate of European adolescents included in the HELENA study. Arch Public Health 70:14
28. Moreno LA, Gonzalez-Gross M, Kersting M, Molnar D, De Henauw S, Beghin L et al (2008) Assessing, understanding and modifying nutritional status, eating habits and physical activity in European adolescents: the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) study. Public Health Nutr 11:288–299
29. Moreno LA, De Henauw S, Gonzalez-Gross M, Kersting M, Molnar D, Gottrand F, Barrios L et al (2008) Design and implementation of the healthy lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study. Int J Obes (Lond) 32(Suppl. 5):S4–S11
30. Beghin L, Castera M, Manios Y, Gilbert CC, Kersting M, De Henauw S et al (2008) Quality assurance of ethical issues and regulatory aspects relating to good clinical practices in the HELENA Cross-Sectional study. Int J Obes (Lond) 32(Suppl. 5):S12–S18
31. Vereecken CA, Covents M, Matthys C, Maes L (2005) Young adolescents' nutrition assessment on computer (YANA-C). Eur J Clin Nutr 59:658–667
32. Vereecken C, Dohogne S, Covents M, Maes L (2010) How accurate are adolescents in portion-size estimation using the computer tool young adolescents' nutrition assessment on computer (YANA-C)? Br J Nutr 103:1844–1850
33. Vereecken CA, Covents M, Sichert-Hellert W, Alvira JM, Le Donne C, De Henauw S et al (2008) Development and evaluation of a self-administered computerized 24-h dietary recall method for adolescents in Europe. Int J Obes (Lond) 32(Suppl. 5):S26–S34

34. Federal Research Centre for Nutrition and Food (2011) Bundeslebensmittelschlüssel (BLS)—German nutrient data base. Karlsruhe. http://bls.nvs2.de. (Accessed 2010)
35. Division of Nutrition, Physical Activity and Obesity National Center for Chronic Disease Prevention and Health Promotion (2008) Research to practice series, no. 5. Low-energy-dense foods and weight management: cutting calories while controlling hunger. Centers for Disease Control and Prevention, Atlanta
36. Black AE (2000) Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate. A practical guide to its calculation, use and limitations. Int J Obes Relat Metab Disord 24:1119–1130
37. Cole TJ, Flegal KM, Nicholls D, Jackson AA (2007) Body mass index cut offs to define thinness in children and adolescents: international survey. BMJ 335:194
38. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD et al (1988) Skinfold equations for estimation of body fatness in children and youth. Hum Biol 60:709–723
39. Tanner JM, Whitehouse RH (1976) Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child 51:170–179
40. Nagy E, Vicente-Rodriguez G, Manios Y, Beghin L, Iliescu C, Censi L et al (2008) Harmonization process and reliability assessment of anthropometric measurements in a multicenter study in adolescents. Int J Obes (Lond) 32(Suppl. 5):S58–S65
41. Gonzalez-Gross M, Breidenassel C, Gomez-Martinez S, Ferrari M, Beghin L, Spinneker A et al (2008) Sampling and processing of fresh blood samples within a European multicenter nutritional study: evaluation of biomarker stability during transport and storage. Int J Obes (Lond) 32(Suppl. 5):S66–S75
42. Department of Epidemiology of the German Institute of Human Nutrition Potsdam-Rehbrücke (2009) Multiple source method (MSM). https://nugo.dife.de/msm/. (Accessed Apr 2010)
43. IOM (2005) Dietary reference intakes. http://www.iom.edu/Global/News%20Announcements/~/media/C5CD2DD7840544979A549EC47E56A02B.ashx. (Accessed 1 May 2011)
44. European food safety authority (2010) Scientific Opinion on Dietary Reference Values for carbohydrates and dietary fibre. EFSA J 8:1462
45. Aeberli I, Kaspar M, Zimmermann MB (2007) Dietary intake and physical activity of normal weight and overweight 6 to 14 year old Swiss children. Swiss Med Wkly 137:424–430
46. Ortega RM, Requejo AM, Andres P, Lopez-Sobaler AM, Redondo R, Gonzalez-Fernandez M (1995) Relationship between diet composition and body mass index in a group of Spanish adolescents. Br J Nutr 74:765–773
47. O'Neil CE, Zanovec M, Keast DR, Fulgoni VL III, Nicklas TA (2011) Nutrient contribution of total and lean beef in diets of US children and adolescents: National Health and Nutrition Examination Survey 1999–2004. Meat Sci 87:250–256
48. Murakami K, Miyake Y, Sasaki S, Tanaka K, Arakawa M (2011) Dietary glycemic index and glycemic load in relation to risk of overweight in Japanese children and adolescents: the Ryukyus Child Health Study. Int J Obes (Lond) 35(7):925–936
49. Li Y, Zhai F, Yang X, Schouten EG, Hu X, He Y et al (2007) Determinants of childhood overweight and obesity in China. Br J Nutr 97:210–215
50. Keast DR, Fulgoni VL III, Nicklas TA, O'Neil CE (2013) Food sources of energy and nutrients among children in the United States: National Health and Nutrition Examination Survey 2003–2006. Nutrients 5:283–301
51. Wanders AJ, van den Borne JJ, de Graaf C, Hulshof T, Jonathan MC, Kristensen M et al (2011) Effects of dietary fibre on subjective appetite, energy intake and body weight: a systematic review of randomized controlled trials. Obes Rev 12:724–739
52. Parikh S, Pollock NK, Bhagatwala J, Guo DH, Gutin B, Zhu H et al (2012) Adolescent fiber consumption is associated with visceral fat and inflammatory markers. J Clin Endocrinol Metab 97:E1451–E1457
53. Berkey CS, Rockett HR, Field AE, Gillman MW, Frazier AL, Camargo CA Jr et al (2000) Activity, dietary intake, and weight changes in a longitudinal study of preadolescent and adolescent boys and girls. Pediatrics 105:E56
54. Cheng G, Karaolis-Danckert N, Libuda L, Bolzenius K, Remer T, Buyken AE (2009) Relation of dietary glycemic index, glycemic load, and fiber and whole-grain intakes during puberty to the concurrent development of percent body fat and body mass index. Am J Epidemiol 169:667–677
55. Murakami K, Sasaki S, Takahashi Y, Uenishi K, Yamasaki M, Hayabuchi H et al (2007) Nutrient and food intake in relation to serum leptin concentration among young Japanese women. Nutrition 23:461–468
56. Sartorelli DS, Franco LJ, Cardoso MA (2008) High intake of fruits and vegetables predicts weight loss in Brazilian overweight adults. Nutr Res 28:233–238
57. Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, Colditz GA et al (2002) Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. Am J Clin Nutr 76:535–540
58. Samra RA, Anderson GH (2007) Insoluble cereal fiber reduces appetite and short-term food intake and glycemic response to food consumed 75 min later by healthy men. Am J Clin Nutr 86:972–979
59. Zanovec M, O'Neil CE, Cho SS, Kleinman RE, Nicklas TA (2010) Relationship between whole grain and fiber consumption and body weight measures among 6- to 18-year-olds. J Pediatr 157:578–583
60. Mumford SL, Schisterman EF, Siega-Riz AM, Gaskins AJ, Wactawski-Wende J, VanderWeele TJ (2011) Effect of dietary fiber intake on lipoprotein cholesterol levels independent of estradiol in healthy premenopausal women. Am J Epidemiol 173:145–156
61. Kynde I, Johnsen NF, Wedderkopp N, Bygbjerg IB, Helge JW, Heitmann BL (2010) Intake of total dietary sugar and fibre is associated with insulin resistance among Danish 8-10- and 14-16-year-old girls but not boys. European Youth Heart Studies I and II. Public Health Nutr 13:1669–1674
62. Dennison BA, Levine DM (1993) Randomized, double-blind, placebo-controlled, two-period crossover clinical trial of psyllium fiber in children with hypercholesterolemia. J Pediatr 123:24–29
63. Anderson JW, Riddell-Mason S, Gustafson NJ, Smith SF, Mackey M (1992) Cholesterol-lowering effects of psyllium-enriched cereal as an adjunct to a prudent diet in the treatment of mild to moderate hypercholesterolemia. Am J Clin Nutr 56:93–98
64. Kaline K, Bornstein SR, Bergmann A, Hauner H, Schwarz PE (2007) The importance and effect of dietary fiber in diabetes prevention with particular consideration of whole grain products. Horm Metab Res 39:687–693
65. Dorgan JF, Liu L, Barton BA, Deshmukh S, Snetselaar LG, Van Horn L et al (2011) Adolescent diet and metabolic syndrome in young women: results of the Dietary Intervention Study in Children (DISC) follow-up study. J Clin Endocrinol Metab 96:E1999–E2008