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Low consumption of fruit and vegetables and risk of chronic disease: a review of the epidemiological evidence and temporal trends among Spanish graduates

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Abstract

Objective: To review the evidence on the association between fruit and vegetable (F&V) consumption and risk of chronic disease, and to assess trends in the prevalence of low F&V consumption.
Design: Systematic review and cross-sectional analyses of a Mediterranean cohort.
Setting: The Seguimiento University of Navarra (SUN) project (Spanish dynamic cohort of graduates).
Subjects: A systematic review of prospective studies aimed to assess the relationship between fruit and/or vegetables consumption and chronic disease incidence was conducted. We also assessed 18 457 university graduates (59·4 % women; mean age = 39 (SD 12) years) enrolled in a dynamic cohort with permanently open recruitment. Baseline data were collected between 1999 and 2010 using a validated 136-item FFQ. Four definitions for low F&V consumption were used (<400 g/d, <200 g/4184 kJ (1000 kcal) per d, ≤2 servings/d and ≤1 serving/d). Multivariate-adjusted cross-sectional associations between the prevalence of low F&V consumption and the year of recruitment were estimated.
Results: The systematic review found that a high F&V consumption is inversely associated with CVD incidence and mortality. This association is not so clear for cancer. Inconsistent findings have been reported for diabetes. In all, 13 % of participants in the SUN cohort did not meet the goal of consuming at least 400 g/d of F&V and 2·1 % of them did not reach >1 serving/d. Between 1999 and 2010 the consumption of F&V significantly increased.
Conclusions: Even among health-conscious university graduates, low F&V consumption is fairly prevalent. Although the temporal trends suggest an improvement, preventive strategies addressed to increase F&V consumption are needed.

Keywords
Cohort
CHD
Cancer
Diabetes

Chronic non-communicable diseases account for 60 % of all deaths worldwide[1]. Sufficiently high consumption of fruit and vegetables (F&V) has been related to a lower risk of major chronic disease and eating at least five servings of F&V per day has been extensively recommended to promote longevity and to reduce the risks of CVD and cancer[2–4]. Moreover, low F&V consumption has been ranked among the twelve leading risk factors responsible for avoidable mortality in the USA[5] and has been reported to be responsible for 2·7 million deaths globally[4].

Our aim was to review the available epidemiological evidence on F&V consumption and the risk of major chronic disease and to appraise the temporal trend in the prevalence of low F&V consumption in a Mediterranean cohort of university graduates.

Methods

Literature review

We searched electronic databases (1980–2009) for published prospective studies that assessed the relationship between the consumption of fruit and/or vegetables and the incidence or mortality from CVD, cancer or diabetes and included a quantitative assessment of F&V intake.

The Seguimiento University of Navarra prospective cohort

The Seguimiento University of Navarra (SUN) cohort is a Mediterranean epidemiological study with a prospective design. All participants are university graduates. The SUN cohort is patterned after the models of the Nurses' Health

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Study or the Health Professionals Follow-up Study, which are composed only of highly educated participants, thus ensuring a more complete follow-up and a better quality of self-reported information. A major difference of the SUN cohort is that the recruitment is permanently open, because a dynamic design has been chosen for this cohort. New participants have been admitted every year since 1999, thus allowing for estimation of temporal trends in lifestyle and food habits of recruited participants. Extensive information about the methods, objectives and design of this cohort has been published previously[6–8]. Information on exposure was gathered by mailed questionnaires at baseline. Outcomes were assessed through follow-up questionnaires collected biennially.

A previously validated and extensively used 136-item FFQ[9–11] was collected at baseline together with a wide array of information about sociodemographic characteristics, anthropometric variables, lifestyles and health-related habits[8]. The baseline questionnaire included 554 items[8]. The validity of self-reported information has been assessed in specific studies using subsamples of the SUN cohort[12–15].

Up to May 2010, 20 426 participants had been admitted to the SUN cohort and had completed their baseline evaluation. From them, we excluded participants who reported very low or very high values for total energy intake according to predefined limits[16], because they were more likely to have failed to properly complete the questionnaire (<3347 kJ (<800 kcal)/d in men or <2092 kJ (<500 kcal)/d in women or >16 736 kJ (>4000 kcal)/d in men or >14 644 kJ (>3500 kcal)/d in women) (*n* 1969). Therefore, 18 457 participants were included in the following analyses.

The present study was approved by the Institutional Review Board of the University of Navarra. Voluntary completion of the first questionnaire was considered to imply informed consent.

Definition of low fruit and vegetable consumption

The FFQ included sixteen items for fruits and eleven items for vegetables (plus potatoes and French fries, which were excluded). Each item in the FFQ included a typical portion size[9–11]. Daily food consumption was estimated by multiplying the portion size by the consumption frequency, for each food item (nine options ranging from never or almost never to six or more times per day). A team of trained dietitians updated the nutrient databank using the latest available information included in food composition tables for Spain. We used three alternative operative definitions for low F&V consumption: (i) ≤400 g/d; (ii) ≤200 g/4184 kJ (1000 kcal)/d; and (iii) ≤2 servings/d. The operative definition of very low F&V consumption was ≤1 serving/d.

Statistical methods

Differences in sociodemographic or behavioural characteristics of participants according to the period of recruitment were estimated with one-way ANOVA or Pearson's χ^2.

Logistic regression models were fit with each of the definitions for low or very low F&V consumption as outcome. Potential confounders included in all models were age, sex and the higher educational status achieved by the participant (four levels: only college, postgraduate school, masters degree, doctoral degree). Tests of linear trend were conducted using the likelihood ratio test with the calendar year of entering the cohort introduced as a continuous independent variable and adjusting for the potential confounders. All these analyses were repeated after stratifying by sex. In sensitivity analyses, we also additionally adjusted for baseline BMI (continuous), marital status (married/others), current smoking at baseline, leisure-time physical activity (METS-h/week, continuous) and alcohol consumption (g/d, continuous).

All *P* values presented are two-tailed; $P<0{\cdot}05$ was considered statistically significant. The Statistical Package for the Social Sciences software package for Windows version 15·0 (SPSS Inc., Chicago, IL, USA) was used for statistical analyses.

Results

Literature review

Table 1 shows the results of some recently published meta-analyses on F&V consumption and the risk of CVD. All of them included only prospective cohort studies. A pooled analysis of eleven cohort studies conducted by Pereira *et al.*[17] found that fruit fibre was inversely associated with the incidence of CHD events and also with CHD mortality. Null associations were found for vegetable fibre. Subsequently, two meta-analyses on F&V intake and CHD were published[18,19]. The meta-analysis conducted by Dauchet *et al.*[18] found stronger inverse associations for fruit than for vegetable intake. The meta-analysis by He *et al.*[19] showed an inverse dose–response trend.

In addition to the traditional narrative review by Ness and Powles[20], two recent meta-analyses of fruit or vegetable consumption and stroke risk have been published[21,22]. The meta-analysis by Dauchet[21] showed that stroke risk was reduced by 11 % for each additional serving/d of fruit and by a non-significant 3 % for each additional serving/d of vegetables. The estimates of relative risk in the meta-analysis by He *et al.*[22] were 0·72 (95 % CI 0·66, 0·79) for fruits and 0·81 (95 % CI 0·72, 0·90) for vegetables for the comparison between the highest (>5 servings/d) and the lowest (<3 servings/d) intake categories. There were no statistically significant differences in the risk of stroke when the intermediate category of vegetable consumption was compared with the lowest category of consumption. Some meta-analyses suggested the possibility of publication bias (some small studies with null results might have remained unpublished), but

Table 1 Recent meta-analyses of F&V consumption and the risk of CVD

First author(ref.)	Year	Exposure	Outcome	Number of studies	Pooled RR	95 % CI	Comments
Pereira[17]	2004	Fruit fibre (≥10 g/d)	CHD	11	0·84	0·70, 0·99	Pooled analysis; the inverse association was also apparent for cereal fibre and fatal CHD
		Vegetable fibre (≥10 g/d)	CHD	11	1·00	0·88, 1·13	
		Fruit fibre (≥10 g/d)	Fatal CHD	10	0·70	0·55, 0·89	
		Vegetable fibre (≥10 g/d)	Fatal CHD	10	1·00	0·82, 1·23	
Dauchet[18]	2006	Fruit (≥1 serving/d)	CHD	7	0·93	0·89, 0·96	Evidence of publication bias, heterogeneity in the association for vegetable consumption and CHD
		Vegetable (≥1 serving/d)	CHD	8	0·95	0·92, 0·99	
He[19]	2007	F&V (3–5 *v.* <3 servings/d)	CHD	12	0·93	0·86, 1·00	The inverse association for 3–5 servings of F&V *v.* <3 servings/d was borderline significant ($P = 0·06$)
		F&V (>5 *v.* <3 servings/d)	CHD	12	0·83	0·77, 0·89	
		Fruit (1·3–2·0 *v.* <1·3 servings/d)	CHD	9	0·90	0·83, 0·98	
		Fruit (>2·0 *v.* <1·3 servings/d)	CHD	9	0·87	0·80, 0·95	Significant heterogeneity was found that also remained within many subgroup analyses. No evidence of substantial publication bias
		Vegetables (1·7–3·0 *v.* <1·7 servings/d)	CHD	9	0·92	0·87, 0·97	
		Vegetables (>3·0 *v.* <1·7 servings/d)	CHD	9	0·84	0·76, 0·92	
Dauchet[21]	2005	Fruit (≥1 serving/d)	Stroke	6	0·89	0·85, 0·93	No evidence of heterogeneity or publication bias. An inverse dose-response trend for fruit was apparent
		Vegetable (≥1 serving/d)	Stroke	4	0·97	0·92, 1·02	
He[22]	2007	F&V (3–5 *v.* <3 servings/d)	Stroke	9	0·89	0·83, 0·97	Consistent results for >5 *v.* <3 servings/d
		F&V (>5 *v.* <3 servings/d)	Stroke	12	0·74	0·69, 0·79	Some heterogeneity in subgroups for 3–5 *v.* <3 servings/d
		Fruit (2–3 *v.* ≤1 serving/d)	Stroke	6	0·82	0·89, 0·98	A small publication bias was suggested
		Fruit (>3 *v.* ≤1 serving/d)	Stroke	6	0·72	0·66, 0·79	
		Vegetables (2–4 *v.* ≤1 serving/d)	Stroke	6	0·93	0·82, 1·06	
		Vegetables (>4 *v.* ≤1 serving/d)	Stroke	6	0·81	0·72, 0·90	

F&V, fruit and vegetables; ref., reference; RR, relative risk.

the likely magnitude of this bias was weak (Table 1). Stronger protection by fruit than for vegetables against CVD is also in agreement with other recent cohort studies, not included in the above cited meta-analyses, such as two large Japanese cohorts,[23,24] the Shanghai Women's Health Study[25] and the Finnish Mobile Clinic cohort[26], but not with another Japanese cohort assessing only fatal cases of CVD[27] or a recent cohort in France and Northern Ireland that found inverse associations for F&V and CVD only among smokers[28]. However, for the combined consumption of F&V, most cohort studies, also those not included in the meta-analyses, showed inverse significant associations.

Table 2 shows the available results of two meta-analyses[29,30] on the relationship between F&V consumption and type 2 diabetes incidence. Although an inverse trend was suggested by some individual studies and the consumption of green leafy vegetables was inversely associated with stroke risk in one of them[24], the overall results were largely non-significant.

The largest study conducted to assess the relationship between F&V consumption and cancer risk included nearly 400 000 European men and women followed up for 9 years but found only a weak reduction in risk (4 %) in spite of observing approximately 30 000 cancers in total[31]. Previous beliefs in strong protection against cancer attributed to F&V consumption were overly optimistic and were based mainly on results from case–control studies with a strong potential for bias[32,33]. A comprehensive review of case–control and cohort studies reported that in prospective cohort studies, not so prone to biases, the risk reduction was significant only for cancers of the lung and bladder, and only for fruit[33]. A pooled analysis of thirteen prospective studies also found an inverse association for renal cell cancer[34]. A recent comprehensive assessment of the available evidence on the relationship between the consumption of F&V and cancer risk does not support a strong benefit[35].

Fruit and vegetable consumption in the participants of the Seguimiento University of Navarra cohort

Table 3 shows that the characteristics of participants entering the SUN cohort during different periods (1999–2010) were not completely homogeneous. However, in spite of the statistically significant results for all variables except leisure-time physical activity, the absolute magnitude of the differences was small.

The prevalence of low or very low F&V consumption was always higher in men than in women, regardless of the definition used (Table 4). The temporal trend suggested that the adequate F&V consumption improved with time in university graduates entering this cohort. All tests for linear trend were statistically significant, suggesting that with each calendar year the prevalence of low fruit consumption was reduced by approximately 2–11 %.

Table 2 Recent meta-analyses and systematic reviews of F&V consumption and the risk of type 2 diabetes

First author[ref.]	Year	Exposure	Number of studies	Pooled RR	95 % CI	Comments
Hamer[29]	2007	Fruit (≥3 servings/d *v.* lowest category)	4	1·01	0·88, 1·15	Significant heterogeneity between studies. A meta-analysis of antioxidant intake and diabetes was also conducted with RR = 0·87 (0·79, 0·98)
		Vegetable (≥3 servings/d *v.* lowest category)	4	0·97	0·86, 1·10	
		F&V (≥5 servings/d *v.* lowest category)	4	0·96	0·79, 1·17	
Carter[30]	2010	Vegetables (highest *v.* lowest)	5	0·91	0·76, 1·10	Significant heterogeneity between studies. No evidence of publication bias. An increase of 1·15 servings in green leafy vegetables was associated with a 14 % decrease in risk
		Fruit (highest *v.* lowest)	5	0·93	0·83, 1·05	
		F&V (highest *v.* lowest)	4	1·00	0·92, 1·09	
		Green leafy vegetables (highest *v.* lowest)	4	0·86	0·77, 0·96	

F&V, fruit and vegetables; ref., reference; RR, relative risk.

However, when the first definition of low F&V consumption (≤400 g/d) was used among men, the results only approached statistical significance ($P = 0{\cdot}06$). The results were similar and remained statistically significant (data not shown) after additionally adjusting the models for baseline BMI, marital status, current smoking at baseline, leisure-time physical activity and alcohol consumption.

Discussion

The health promotion advice to select diets largely based on plant foods and to increase the consumption of F&V has not changed in the past 50 years[36]. However, the actual global levels of F&V consumption are far from optimal[4,5,35]. Whereas the potential benefits of F&V against cancer incidence are only weak and restricted to certain types of cancer, the results of large cohort studies consistently provide enough evidence to support strong benefits against CVD. In particular, fruit consumption is associated with relative reductions in risk higher than 25 % for stroke and higher than 15 % for CHD. The commonly proposed goal of consuming at least five portions (or at least 400 g) of vegetables and fruits per day[4,35] to reduce the risk of CHD or stroke is well supported by prospective epidemiological evidence[37]. There is, however, a need for further evidence regarding diabetes prevention.

The more recent results of cohort studies, as compared with previous case–control studies, provide only weak evidence of the association of F&V consumption with reduced cancer risk. The inconsistencies between cohort and case–control studies on this issue may be related to recall and selection biases in case–control studies[33]. A lower participation rate among controls than among cases is very likely in most case–control scenarios. Control subjects who agree to participate are typically very health conscious persons who tend to consume more F&V than those who did not choose to participate[32]. This would lead to an apparent inverse association of F&V with cancer in case–control studies even if that association is not true. These false benefits might be further exaggerated if the groups of control and cases differentially recall or report their past diets due to the fact that many cases recently received a dismal diagnosis, whereas controls were not under this psychological impact.

On the other hand, an underestimation of a true inverse association between F&V consumption and the risk of chronic disease may happen in any epidemiological study because of imprecise dietary measurements, regression-dilution bias[38] or limited between-subjects variability in F&V consumption[33]. Some degree of non-differential misclassification (measurement error) is unavoidable in nutritional epidemiology and may account for losing the ability to detect some real associations if they are not strong enough. However, in a large cohort study that

Table 3 Characteristics of graduates entering the SUN cohort according to the recruitment period (1999–2010)

	1999–2001 (*n* 6624)		2002 (*n* 3091)		2003–2004 (*n* 4036)		2005–2007 (*n* 3578)		2008–2010 (*n* 1128)		
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value*
% Women	60		57		57		67		51		<0·001
Age (years)	37	13	37	11	42	12	40	12	39	14	<0·001
University degree†											
% Only college	35		28		39		16		19		<0·001
% Masters degree	7		8		4		10		18		
% PhD	10		11		11		10		16		
% Married	45		51		61		53		47		<0·001
% Current smokers	25		25		18		18		17		<0·001
BMI (kg/m^2)	23·3	3·4	23·3	3·5	24·2	3·5	23·6	3·8	23·7	3·6	<0·001
Alcohol consumption (g/d)	6·5	10·1	6·6	9·8	7·5	11·6	6·7	10·1	6·8	9·3	<0·001
Physical activity (METS-h/week)	24	21	24	23	25	23	24	22	25	23	0·08

METS, metabolic equivalents during leisure time.
Values are mean and standard deviation unless otherwise stated.
*The χ^2 or one-way ANOVA.
†Percentages do not add 100 % because there is a fourth category (postgraduates) between 'only college' and 'masters degree'.

Table 4 Trends in the prevalence of low F&V consumption among graduates entering the SUN cohort (1999–2010)

		Low F&V consumption									Very low consumption		
		≤400 g/d			≤200 g/1000 kcal/d			≤2 servings/d			≤1 serving/d		
			Adjusted*			Adjusted*			Adjusted*			Adjusted*	
Total	*n*	%	OR	95 % CI	%	OR	95 % CI	%	OR	95 % CI	%	OR	95 % CI
1999–2001	6624	13·6	1·00	Ref.	19·4	–	–	10·3	–	–	2·3	–	–
2002	3091	15·2	1·08	0·95, 1·22	20·3	1·00	0·89, 1·11	12·1	1·16	1·01, 1·33	2·6	1·06	0·80, 1·40
2003–2004	4036	13·1	1·09	0·97, 1·23	16·8	0·99	0·89, 1·11	9·2	1·02	0·88, 1·17	2·2	0·99	0·76, 1·31
2005–2007	3578	8·5	0·65	0·57, 0·75	11·2	0·60	0·53, 0·68	5·8	0·58	0·49, 0·68	1·4	0·61	0·43, 0·85
2008–2010	1128	14·4	1·02	0·84, 1·23	16·7	0·78	0·66, 0·93	9·8	0·90	0·73, 1·12	1·3	0·52	0·30, 0·90
Overall	18 457	12·8	–	–	17·2	–	–	9·4	–	–	2·1	–	–
Per 1+ year			0·97	0·95, 0·98		0·94	0·93, 0·96		0·95	0·93, 0·97		0·93	0·89, 0·97
P for trend		<0·001	<0·001		<0·001	<0·001		<0·001	<0·001		<0·001	0·001	
Men													
1999–2001	2674	18·5	1·00	Ref.	27·4	1·00	Ref.	13·5	1·00	Ref.	3·0	1·00	Ref.
2002	1327	19·4	1·02	0·86, 1·21	27·8	0·95	0·82, 1·11	14·5	1·06	0·88, 1·29	2·6	0·86	0·57, 1·29
2003–2004	1744	17·3	1·09	0·92, 1·28	23·5	1·01	0·87, 1·17	12·1	1·05	0·87, 1·27	2·9	1·09	0·75, 1·59
2005–2007	1198	14·4	0·80	0·66, 0·98	18·5	0·68	0·57, 0·81	9·6	0·73	0·57, 0·91	2·0	0·67	0·41, 1·09
2008–2010	554	16·8	0·93	0·73, 1·20	21·3	0·75	0·60, 0·95	11·6	0·86	0·64, 1·15	1·4	0·50	0·24, 1·05
Per 1+ year			0·98	0·95, 1·00	–	0·95	0·93, 0·97	–	0·96	0·94, 0·99	–	0·94	0·89, 1·00
P for trend		0·006	0·06		<0·001	<0·001		0·001	0·01		0·03	0·04	
Women													
1999–2001	3950	10·4	1·00	Ref.	14·0	1·00	Ref.	8·1	1·00	Ref.	1·9	1·00	Ref.
2002	1764	12·1	1·16	0·97, 1·39	14·7	1·05	0·89, 1·24	10·3	1·28	1·05, 1·55	2·6	1·29	0·88, 1·88
2003–2004	2292	9·9	1·10	0·92, 1·32	11·8	0·97	0·83, 1·14	7·0	0·98	0·80, 1·21	1·6	0·88	0·59, 1·32
2005–2007	2380	5·5	0·53	0·43, 0·65	7·4	0·53	0·44, 0·64	3·8	0·46	0·36, 0·59	1·1	0·56	0·35, 0·90
2008–2010	574	12·0	1·14	0·86, 1·50	12·2	0·83	0·63, 1·09	8·2	0·97	0·70, 1·35	1·2	0·53	0·23, 1·23
Per 1+ year			0·95	0·93, 0·98	–	0·94	0·91, 0·96	–	0·93	0·91, 0·96	–	0·92	0·86, 0·97
P for trend		<0·001	<0·001		<0·001	<0·001		<0·001	<0·001		0·006	0·003	

F&V, fruit and vegetables; SUN cohort, Seguimiento University of Navarra cohort; Ref., referent category.
Multivariate-adjusted for age, sex (in the models including men and women) and educational level.

observed no association between F&V and total cancer, a 30 % lower incidence of CHD or stroke was found for ≥5 servings/d *v.* <1·5 servings/d[39]. It is revealing that in the same cohort, with identical potential for measurement errors and with the same between-subjects variability in intake, contrasting results were observed for cancer and for CVD. That study strongly supported that the benefits of F&V accrue mainly because of their effects in cardiovascular protection but not so much because of their cancer preventive effects.

In summary, the benefits of F&V consumption for cardiovascular health are well substantiated by empirical epidemiological research. As CVD is the leading cause of global mortality, the promotion of F&V consumption represents a priority for global public health. In this context, the assessment of trends among highly educated subjects might be important because of the potential exemplary role that these sectors of the population with higher levels of education may play in achieving behavioural changes in society at large. Their lifestyles

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tend to be eventually adopted by the rest of the society. The assessment of trends among university graduates is a uniquely appropriate setting to provide the knowledge to design adequate intervention strategies to enhance the adoption of healthy eating habits[40,41].

In our Mediterranean cohort of university graduates (the SUN project), we found that the prevalence of adequate consumption of F&V has recently increased in Spanish university graduates, with a highly significant trend for improvement. This improvement might be related to better information and to successful public health efforts to promote a healthy diet in Spain. Sectors of the population with a higher educational level might be more easily reached by these efforts and might be more likely to adopt healthier diets.

Our study may have some potential limitations. A potential caveat is related to possible unmeasured confounders, as we only adjusted for age, sex and education. Some other baseline characteristics of recruited participants for this cohort might have changed during the assessment period (1999–2010). However, additional adjustment for potentially important known confounders (BMI, alcohol intake, smoking and physical activity) did not substantially change the results with respect to the analyses presented in the tables. In fully adjusted models, the P values for linear trend strongly suggested a decreasing trend for low F&V consumption during the assessment period ($P = 0{\cdot}001$ for ≤400 g/d; $P < 0{\cdot}001$ for ≤200 g/4184 kJ (1000 kcal)/d; $P < 0{\cdot}001$ for ≤2 servings/d; $P = 0{\cdot}002$ for ≤1 serving/d). Therefore, we do not consider residual confounding as the most likely explanation for our results.

Social desirability bias might have partially accounted for an apparent higher consumption of F&V. However, to be able to explain the observed temporal trend, this social desirability bias should have increased with calendar time. We do not have any evidence to support this possibility. The criteria for admitting participants in the cohort and the recruitment strategies remained essentially the same for the SUN cohort during the assessed period. However, the adjustment for other lifestyle and sociodemographic characteristics of recruited participants renders them more comparable. In addition, in the design of the SUN cohort, our aim was not to gather a 'representative' sample in the statistical sense of being a probability sample of a target population. We intended to obtain a fairly homogenous cohort with the ability to conduct valid within-cohort comparisons. Our goal was to select a study group for homogeneity with respect to important confounders, for highly cooperative behaviour and for availability of accurate information, as recommended in epidemiological research[42].

Taking into account these characteristics of our cohort, we acknowledge that our absolute estimates for the prevalence of low F&V consumption would be overly optimistic to be applied to the less-educated sectors of the population and that it would be inappropriate to generalise these findings to the general Spanish population. We can only conclude that in this well-educated Mediterranean cohort the adequacy of F&V consumption has improved in the past 10 years, but the room for improvement is still large.

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