Lower lifetime dietary fiber intake is associated with carotid artery stiffness: the Amsterdam Growth and Health Longitudinal Study[1–3]

Roel JJ van de Laar, Coen DA Stehouwer, Bas CT van Bussel, Saskia J te Velde, Martin H Prins, Jos WR Twisk, and Isabel Ferreira

ABSTRACT

Background: Fiber intake is associated with lower cardiovascular disease risk. Whether arterial stiffness is influenced by lifetime fiber intake is not known. Any such association could explain, at least in part, the cardioprotective effects attributed to fiber intake.

Objective: The objective was to investigate whether a lower intake of fiber (and fiber-rich foods) throughout the course of young life (ie, from adolescence to adulthood) is associated with arterial stiffness in adulthood.

Design: This was a longitudinal cohort study among 373 participants in whom dietary intake was assessed between the ages of 13 to 36 y (2–8 repeated measures, median of 5), and arterial stiffness estimates of 3 large arteries (ultrasonography) were ascertained at age 36 y.

Results: After adjustment for sex, height, total energy intake, and other lifestyle variables, subjects with stiffer carotid arteries consumed less fiber (in g/d) during the 24-y study than did those with less stiff carotid arteries, as defined on the basis of the highest compared with the lowest sex-specific tertiles of the distensibility and compliance coefficients (reversed) and Young's elastic modulus: −1.9 (95% CI: −3.1, −0.7), −2.3 (−3.5, −1.1), and −1.3 (−2.5, −0.0), respectively. Furthermore, subjects with stiffer carotid arteries were characterized by a lower lifetime consumption of fruit, vegetables, and whole grains—deleterious associations that could be explained, to a great extent, by related low fiber intake.

Conclusions: Lower lifetime intake of fiber during the course of young age is associated with carotid artery stiffness in adulthood. Promoting consumption of fiber-rich foods among the young may offer a means to prevent accelerated arterial stiffening in adulthood and related cardiovascular sequelae. *Am J Clin Nutr* 2012;96:14–23.

INTRODUCTION

Arterial stiffness may cause cardiovascular disease (CVD)[4] by contributing to increased systolic blood pressure, increased cardiac afterload and diminished cardiac perfusion (1). Arterial stiffness–related complications, such as coronary heart disease (CHD), stroke, heart failure, and mortality, generally occur after the fifth decade of life (2, 3), but the process of arterial stiffening starts much earlier as a result of exposure to risk factors (RFs) during a preclinical phase that may last for decades. Indeed, adverse levels of cardiovascular RFs in childhood/adolescence, such as low vigorous habitual physical activity and elevated (central) body fatness and blood pressure, have been shown to be associated with arterial stiffness in adulthood (4–8). Given that lifelong engagement in unhealthy lifestyles may be established in childhood (9), it is important to identify already at a young age modifiable RFs that may influence arterial stiffness later in life.

Low dietary fiber intake may be one such RF. Several observational studies have shown fiber to be inversely associated with the risk of incident CHD and stroke (10–12) and all-cause and cardiovascular mortality (13). Current recommendations thus suggest increasing fiber intake through higher consumption of fruit, vegetables, and whole grains to reduce CVD risk in the general population (14). A higher fiber intake may prevent arterial stiffening, as suggested by a recent study showing that individuals with the highest consumption of fruit and vegetables during childhood/adolescence and adulthood had lower levels of aortic pulse wave velocity (PWV) in adulthood (15). Whether these associations can be attributed to the fiber content of these foods and thus may hold also for other foods rich in fiber, such as whole-grain products, is not known.

[1] From the Department of Internal Medicine (RJJvdL, CDAS, BCTvB, and IF), Cardiovascular Research Institute Maastricht (RJJvdL, CDAS, and IF), CAPHRI School for Public Health and Primary Care (RJJvdL, MHP, and IF), Department of Clinical Epidemiology and Medical Technology Assessment (MHP and IF), Maastricht University Medical Centre+, Maastricht, Netherlands; and the EMGO+ Institute (SJtV and JWRT), Department of Epidemiology and Biostatistics (SJtV and JWRT), Department of Public and Occupational Health (JWRT), VU University Medical Center, Amsterdam, Netherlands.

[2] IF was supported by a postdoctorate research grant (2006T050) from the Netherlands Heart Foundation to conduct the research described in this article. The Amsterdam Growth and Health Longitudinal Study has been supported by research grants from the Foundation for Educational Research; The Dutch Prevention Fund; The Netherlands Heart Foundation; The Dutch Ministry of Public Health, Well Being and Sport; the Dairy Foundation on Nutrition and Health; The Netherlands Olympic Committee/Netherlands Sports Federation; Heineken BV; and The Scientific Board on Smoking and Health.

[3] Address correspondence to I Ferreira, Department of Clinical Epidemiology & Medical Technology Assessment/ Department of Internal Medicine, Maastricht University Medical Centre, P. Debyelaan 25, PO Box 5800, 6202 AZ Maastricht, Netherlands. E-mail: i.ferreira@maastrichtuniversity.nl.

[4] Abbreviations used: CC, compliance coefficient; CHD, coronary heart disease; CVD, cardiovascular disease; DC, distensibility coefficient; E_{inc}, Young's elastic modulus; GEE, generalized estimating equation; PWV, pulse wave velocity; RF, risk factor.

Received August 4, 2011. Accepted for publication April 5, 2012.

First published online May 23, 2012; doi: 10.3945/ajcn.111.024703.

In view of these considerations, we investigated—in a cohort of young individuals in whom dietary intake was repeatedly assessed from adolescence up to adulthood and in whom stiffness estimates of 3 larger arteries were ascertained at the age of 36 y—*1*) whether the lifetime intake of fiber differed between subjects with increasing levels of arterial stiffness at age 36 y and *2*) whether these differences could be attributed to the consumption of foods high in fiber, such as fruit, vegetables, and whole-grain products. Individual levels of arterial stiffness were defined on the basis of local estimates obtained at the central (elastic) carotid and peripheral (muscular) brachial and femoral arteries (4–6) to ascertain the extent to which associations of fiber intake with arterial stiffness differed along the arterial tree. This distinction is important not only from an etiologic point of view but also because stiffness levels of central arteries such as the carotid (2) and aorta (3), but not of peripheral arteries may be stronger predictors of cardiovascular outcome (1).

SUBJECTS AND METHODS

All subjects were participants in the Amsterdam Growth and Health Longitudinal Study, an observational study that started in 1976–1977 with a group of ~600 children aged 13 y from 2 secondary schools in the Netherlands. Since then, repeated measurements of dietary intake and anthropometric, biological, and other lifestyle variables have been obtained 2–8 times (ie, at ages 13, 14, 15, 16, 21, 27, 32, and 36 y; average of 5 repeated measures per individual) during a 24-y follow-up period, as described in detail elsewhere (16). In 2000, when the mean (±SD) ages of the study participants were 36.5 ± 0.5 y, arterial properties of 3 large arteries were ascertained in 373 participants (196 women) (4–6). The current study was confined to these participants, but their levels of dietary (fiber, fiber-rich foods) intake, as well as of other lifestyle and biological RFs, did not differ from those not included in the analyses at any of the earlier time points (data not shown). The study population is therefore representative of the original cohort, and selection bias did not threaten our results. The study was approved by the medical ethical committee of the VU University Medical Center (Amsterdam, Netherlands), and all subjects gave their written informed consent (provided by their parents when participants were 13–16 y of age).

Arterial stiffness

Arterial properties were assessed by means of ultrasonography according to guidelines for user procedures and with the use of reproducible methods and devices (1, 17, 18), as described in detail elsewhere (4–6) and briefly below. All subjects abstained from smoking and alcohol and caffeine-containing beverages on the day the measurements were performed. Measurements in different individuals were distributed throughout the day and started after the subjects had been resting in a supine position for 15 min in a quiet temperature-controlled room. Properties of the right common carotid (10 mm proximal to the beginning of the bulb), brachial (20 mm above the antecubital fossa), and common femoral (20 mm proximal to the flow divider) arteries were obtained with an ultrasound scanner equipped with a 7.5-MHz linear array probe (Pie Medical). The ultrasound scanner was connected to a personal computer equipped with an acquisition system and a vessel wall movement detector software system (Wall Track System 2; Pie Medical) that enabled measurement of the arterial diameter, distention (ΔD), and intima-media thickness as described in detail elsewhere (17, 18).

Throughout the entire period of ultrasound imaging, blood pressure was assessed in the left arm at 5-min intervals with an oscillometric device (model BP-8800; Colin Press-Mate). Brachial pulse pressure was defined as systolic – diastolic pressure, and pulse pressure at the level of the common carotid and femoral arteries was calculated by calibrating the distension waveforms (19). The mean diameter (D), ΔD, and local pulse pressure of 3 consecutive measurements were used to estimate the distensibility coefficient (DC) and compliance coefficient (CC) of each artery as follows (17, 18):

$$\mathrm{DC} = \left(2\Delta\mathrm{D} \times \mathrm{D} + \Delta\mathrm{D}^2\right) / \left(\mathrm{PP} \times \mathrm{D}^2\right) \quad \text{in } 10^{-3}/\mathrm{kPa} \qquad (1)$$

$$\mathrm{CC} = \pi \times \left(2\mathrm{D} \times \Delta\mathrm{D} + \Delta\mathrm{D}^2\right) / 4\mathrm{PP} \quad \text{in } \mathrm{mm}^2/\mathrm{kPa} \qquad (2)$$

The DC reflects the elastic properties, whereas the CC reflects the buffering capacity of the artery at given operating local pressures. From the carotid diameter, DC, and intima-media thickness, the Young's elastic modulus (E_{inc})—an estimate of the intrinsic elastic properties of the vessel wall—was calculated as follows:

$$E_{inc} = \mathrm{D} / (\mathrm{IMT} \times \mathrm{DC}) \quad \text{in } 10^3 \times \mathrm{kPa} \qquad (3)$$

In contrast with the DC and CC, higher E_{inc} values indicate greater arterial stiffness. Therefore, the DCs and CCs were reversed (multiplied by −1) so that higher values represent greater stiffness in agreement with the carotid E_{inc}. Subsequently, we categorized subjects on the basis of the sex-specific tertiles of each stiffness estimate into those with less stiff (ie, lowest tertiles; tertile 1), intermediate (ie, middle tertiles; tertile 2), and stiffer (ie, highest tertiles; tertile 3) arteries.

Dietary assessment

From the age of 13 through 36 y, usual food intake was repeatedly measured by using a previously validated cross-check dietary history (face-to-face) interview based on the method developed by Beal (20) and Marr (21) and adapted to the Amsterdam Growth and Health Longitudinal Study, as described in detail elsewhere (16, 22–24). In brief, participants were asked to recall their usual food intake during the previous month by reporting the frequency, amount, and method of preparation of the foods and drinks (including alcoholic beverages) consumed. The interviews took, on average, 1 h to complete. The amounts were reported in household measures or grams and models were used to illustrate portion sizes. During the 2000 measurement, a newly developed interviewer-administered computer-assisted crosscheck dietary-history method was introduced (23). Computer questions and interview structure were based on the original face-to-face interview. The 2 methods of dietary assessment showed high comparability, although introduction of the computer-assisted method likely caused a reduction of interviewer bias (23).

The mean fiber (in g/d) and total energy (in kcal/d) intakes and intakes of fruit, vegetables, and whole-grain products (all in g/d)

were calculated by using the *1996 Dutch Food Composition Table* (25). Fruit included fresh (citrus and noncitrus), dried, and canned types and fruit juices. Potatoes and legumes were included in the vegetable consumption.

Covariates

Throughout the 24-y study period, other lifestyle (ie, habitual physical activity and smoking behavior), anthropometric (ie, body height, weight, and skinfold thicknesses), and biological (ie, mean arterial pressure and total and HDL cholesterol) RFs were measured as described in detail elsewhere (4–6, 16, 26).

Statistical analyses

We used generalized estimating equations (GEEs) to estimate the mean differences in fiber intake during the 24-y study period between subjects in the highest compared with those in the lowest sex-specific tertiles of each stiffness estimate at age 36 y, or, in other words, between subjects with stiffer and those with less stiff carotid, brachial, and femoral arteries (4–6). GEEs take into account the correlation between repeated observations within the same subject and have the advantage of handling the data of subjects with varying numbers of and unequally time-spaced observations (27). All analyses were adjusted for sex, height, and time (model 1). We have also added interaction terms between time and groups to this model to ascertain whether the strength of the differences differed at any specific age (critical period) throughout the course of the longitudinal study. Results hereby obtained were displayed graphically and reflect the life-course trajectories of fiber intake, from adolescence to adulthood, by levels of arterial stiffness at the age of 36 y (4, 5). The mean differences in lifetime fiber intake between groups with increasing levels of arterial stiffness were further adjusted for potential confounders, ie, total energy intake (kcal/d), habitual physical activity (metabolic equivalents/wk), smoking behavior (yes or no), and alcohol intake (g/wk), as measured throughout the whole longitudinal period (model 2). Adjustment for time of the day at which arterial measures were obtained did not materially affect the effect estimates, reasons why we did not include this variable in our models. We additionally adjusted for potential mediators [ie, mean arterial pressure, skinfold-thickness ratio (as a measure of central body fatness), and/or total:HDL cholesterol ratio] to ascertain the extent to which any differences in levels of lifetime fiber intake between the groups could be explained by these variables (in which case the differences as obtained in model 2 would be appreciably attenuated—mediation analyses).

GEE models similar to those described above were also used to estimate the mean differences in consumption of fruit, vegetables, and whole-grain products throughout the longitudinal period between subjects with stiffer and those with less stiff arteries at age 36 y. Further adjustments for lifetime fiber intake allowed us to ascertain the extent to which any difference in the lifetime consumption of these foods could be explained by their fiber content and/or the other RFs (*see* also Mediation analyses).

All GEE analyses were carried out with the use of the STATA software package (version 9.2; StataCorp). In all analyses, an exchangeable correlation structure and robust estimation of SEs were used; statistical significance was set at $P < 0.05$ (2-sided).

TABLE 1
Characteristics of the study population throughout the 24-y study period[1]

	Calendar age							
Variables	13 y	14 y	15 y	16 y	21 y	27 y	32 y	36 y
Dietary intake								
Individuals with dietary data (*n*)	231	201	209	192	145	149	346	368
Fiber (g/d)	23.9 ± 6.5[2]	24.7 ± 6.1	25.4 ± 7.0	24.4 ± 6.3	24.2 ± 7.2	22.1 ± 5.6	27.6 ± 8.7	28.3 ± 8.5
Fruit (g/d)	247 ± 133	242 ± 144	239 ± 153	229 ± 147	260 ± 174	205 ± 164	283 ± 196	272 ± 203
Vegetables (g/d)	268 ± 114	297 ± 99	308 ± 106	301 ± 106	299 ± 113	299 ± 108	304 ± 129	278 ± 114
Whole grains (g/d)	87 ± 81	87 ± 78	97 ± 87	107 ± 85	113 ± 81	105 ± 70	122 ± 71	144 ± 80
Total energy intake (1000 kcal/d)	2.46 ± 0.55	2.51 ± 0.59	2.59 ± 0.68	2.55 ± 0.68	2.62 ± 0.73	2.48 ± 0.64	2.60 ± 0.71	2.62 ± 0.70
Other lifestyle risk factors								
HPA (1000 METs/wk)	4.42 ± 1.82	3.99 ± 1.62	3.71 ± 1.61	3.51 ± 1.56	3.28 ± 2.08	3.00 ± 2.01	3.41 ± 2.3	4.88 ± 3.27
Alcohol drinkers (%)	13.5	15.9	33.3	48.2	69.0	72.5	80.3	82.1
Alcohol intake drinkers (g/wk)	7 (5–12)[3]	12 (6–21)	15 (9–40)	24 (10–50)	54 (20–107)	51 (29–115)	60 (26–120)	83 (36–164)
Smoking (%)	1.6	11.0	14.0	17.9	29.9	26.2	20.2	23.5
Biological risk factors								
Mean arterial pressure (mm Hg)[4]	91.9 ± 6.9	91.7 ± 6.6	90.1 ± 6.6	91.8 ± 7.2	95.4 ± 8.0	97.2 ± 8.4	99.6 ± 9.0	100.7 ± 11.0
BMI (kg/m^2)	17.7 ± 1.8	18.4 ± 2.0	19.2 ± 2.1	19.8 ± 2.1	21.4 ± 2.2	22.2 ± 2.3	23.3 ± 2.9	24.1 ± 3.1
Sum of 4 skinfold thicknesses (mm)[5]	32.0 ± 12.0	33.5 ± 14.0	35.3 ± 15.0	38.9 ± 16.6	44.8 ± 17.2	41.9 ± 16.1	47.4 ± 19.2	51.5 ± 18.2
Skinfold-thickness ratio[6]	0.49 ± 0.06	0.51 ± 0.06	0.53 ± 0.06	0.55 ± 0.06	0.58 ± 0.08	0.56 ± 0.08	0.56 ± 0.09	0.57 ± 0.10
Total cholesterol (mmol/L)	4.47 ± 0.72	4.35 ± 0.71	4.29 ± 0.72	4.24 ± 0.77	4.70 ± 0.80	5.09 ± 0.96	4.92 ± 0.86	5.00 ± 0.93
HDL cholesterol (mmol/L)	1.45 ± 0.28	1.41 ± 0.26	1.30 ± 0.25	1.35 ± 0.27	1.29 ± 0.29	1.43 ± 0.38	1.42 ± 0.37	1.41 ± 0.37
Total:HDL cholesterol ratio	3.2 ± 0.7	3.2 ± 0.7	3.4 ± 0.8	3.2 ± 0.7	3.8 ± 0.9	3.8 ± 1.0	3.7 ± 1.2	3.8 ± 1.3

[1] HPA, habitual physical activity; METs, metabolic equivalents.
[2] Mean ± SD (all such values).
[3] Median; IQR in parentheses (all such values).
[4] Measured in the sitting position after ≥5 min of rest.
[5] Determined as the sum of the following skinfold thicknesses: triceps, biceps, subscapular, and suprailiac.
[6] Calculated as follows: (subscapular + suprailiac)/sum of the 4 skinfold thicknesses.

Mediation analyses

We used the *ab* product-coefficient method to investigate the magnitude of the attenuations in mean intakes of fiber or fiber-rich foods after adjustment for potential mediators (*see* details of calculations provided in footnotes to Supplemental Tables 1 and 2 under "Supplemental data" in the online issue) (28). The significance of these attenuations was ascertained by the respective CIs, which were estimated with the use of the RMediation package written for use in R statistical software program (version 2.13.0; The R Foundation for Statistical Computing 2011) (29).

RESULTS

Characteristics of the study population throughout the 24-y study period are presented in **Table 1**. The mean intake of fiber decreased by −1.6 g/d (95% CI: −2.8, −0.4) between the ages of 13 and 27 y and increased thereafter by 5.4 g/d (4.3, 6.6) up to the age of 36 y. The mean levels of each local stiffness estimate across the tertiles are shown in **Table 2**.

Lifetime fiber intake by levels of arterial stiffness at age 36 y

After adjustment for sex, height, and time and as compared with subjects with less stiff arteries (ie, in tertile 1), those with stiffer carotid arteries [ie, in tertile 3 of the DC and CC (both reversed), and the E_{inc}] took less fiber during the 24-y study period: on average −2.6 (−4.0, −1.1), −3.0 (−4.4, −1.6), and −2.1 (−3.5, −0.7) g/d, respectively (**Table 3**; model 1). Trajectory analyses showed that these differences were already present in adolescence and remained fairly stable over time (**Figure 1**). Adjustments for potential confounders (ie, total energy intake and other lifestyle variables) attenuated the differences mentioned above to −1.9 (−3.1, −0.7), −2.3 (−3.5, −1.1), and −1.3 (−2.5 to −0.0) g/d, respectively, which nevertheless remained statistically significant (model 2). Further adjustment for mean arterial pressure, skinfold-thickness ratio, and/or total:HDL cholesterol ratio (model 3) did not materially explain these differences, given their weak longitudinal associations with fiber intake (**Table 4**). Indeed, after adjustment for these RFs, differences in lifetime fiber intake were only slightly attenuated (≤8%), and the magnitude of these attenuations was not statistically significant (*see* Supplemental Table 1 under "Supplemental data" in the online issue; simple and multiple mediation analyses). Qualitatively similar differences in lifetime fiber intake, although of lower magnitude and only statistically significant for the CC, were observed across the tertiles of the femoral (Table 3 and Supplemental Table 1 under "Supplemental data" in the online issue) but not brachial stiffness estimates (data not shown).

Lifetime consumption of fiber-rich foods by levels of arterial stiffness at age 36 y

After adjustment for sex, height, time, and potential confounders (ie, total energy intake and other lifestyle variables),

TABLE 2
Arterial stiffness levels at the age of 36 y according to sex-specific tertiles of each stiffness estimate

Stiffness estimates and sex	Tertile 1 (less stiff)	Tertile 2 (intermediate)	Tertile 3 (stiffer)
Sex (*n*)			
M	59	59	59
F	65	66	65
Common carotid artery			
Distensibility coefficient (10^{-3}/kPa)[1]			
M	32.0 ± 3.4[2]	25.8 ± 1.4	20.7 ± 2.1
F	34.7 ± 4.3	26.5 ± 1.7	19.9 ± 2.3
Compliance coefficient (mm^2/kPa)[1]			
M	1.35 ± 0.20	1.04 ± 0.05	0.80 ± 0.01
F	1.22 ± 0.18	0.91 ± 0.06	0.65 ± 0.09
Young's elastic modulus ($10^3 \cdot$ kPa)			
M	0.35 ± 0.04	0.45 ± 0.02	0.60 ± 0.09
F	0.30 ± 0.04	0.41 ± 0.03	0.56 ± 0.08
Brachial artery			
Distensibility coefficient (10^{-3}/kPa)[1]			
M	22.0 ± 10.5	10.5 ± 1.5	6.2 ± 1.6
F	26.2 ± 7.9	14.1 ± 1.9	7.9 ± 2.3
Compliance coefficient (mm^2/kPa)[1]			
M	0.30 ± 0.10	0.17 ± 0.02	0.10 ± 0.03
F	0.24 ± 0.05	0.14 ± 0.02	0.07 ± 0.2
Common femoral artery			
Distensibility coefficient (10^{-3}/kPa)[1]			
M	9.0 ± 3.1	5.5 ± 0.5	3.3 ± 0.8
F	12.9 ± 3.8	7.4 ± 0.9	4.7 ± 0.9
Compliance coefficient (mm^2/kPa)[1]			
M	0.78 ± 0.22	0.48 ± 0.05	0.29 ± 0.06
F	0.78 ± 0.19	0.45 ± 0.05	0.29 ± 0.06

[1] Distensibility and compliance coefficients were reversed (ie, multiplied by −1) before categorization into tertiles, so that higher tertiles indicate higher arterial stiffness in agreement with the Young's elastic modulus.
[2] Mean ± SD (all such values).

TABLE 3
Comparison of the mean lifetime fiber intakes between subjects with increasing levels of carotid and femoral stiffness at age 36 y[1]

	DC[2]				CC[2]				E_{inc}			
	T2 compared with T1		T3 compared with T1		T2 compared with T1		T3 compared with T1		T2 compared with T1		T3 compared with T1	
Model	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Carotid artery												
1	−1.80	−3.22, −0.39[3,*]	−2.58	−4.01, −1.15[3,‡]	−1.17	−2.62, 0.27	−2.94	−4.36, −1.59[3,‡]	−0.30	−1.73, 1.14	−2.07	−3.46, −0.69[3,†]
2	−1.40	−2.57, −0.24[3,*]	−1.90	−3.13, −0.67[3,†]	−0.69	−1.89, 0.51	−2.32	−3.50, −1.14[3,‡]	0.02	−1.17, 1.22	−1.32	−2.49, −0.14[3,*]
3a	−1.36	−2.53, −0.19[3,*]	−1.79	−3.04, −0.54[3,†]	−0.65	−1.86, 0.55	−2.24	−3.43, −1.05[3,‡]	0.07	−1.13, 1.27	−1.21	−2.41, −0.02*
3b	−1.35	−2.53, −0.18[3,*]	−1.81	−3.07, −0.55[3,†]	−0.66	−1.86, 0.55	−2.24	−3.43, −1.05[3,‡]	0.08	−1.12, 1.28	−1.23	−2.42, −0.04*
3c	−1.37	−2.55, −0.20[3,*]	−1.82	−3.06, −0.59[3,†]	−0.62	−1.83, 0.59	−2.27	−3.46, −1.09[3,‡]	0.06	−1.13, 1.25	−1.25	−2.43, −0.07*
3	−1.31	−2.49, −0.13*	−1.68	−2.96, −0.41[3,*]	−0.58	−1.80, 0.63	−2.16	−3.36, −0.96[3,‡]	0.13	−1.07, 1.34	−1.11	−2.32, 0.09
Femoral artery												
1	−0.60	−1.95, 0.75	−0.87	−2.25, 0.52	−1.74	−3.09, −0.39[3,*]	−1.41	−2.81, −0.01*	—	—	—	—
2	−0.47	−1.65, 0.71	−0.96	−2.19, 0.26	−1.18	−2.34, −0.01*	−1.26	−2.50, −0.02*	—	—	—	—
3a	−0.46	−1.64, 0.72	−0.89	−2.13, 0.34	−1.14	−2.31, 0.02	−1.19	−2.44, 0.06	—	—	—	—
3b	−0.45	−1.62, 0.73	−0.92	−2.15, 0.31	−1.16	−2.33, 0.00	−1.18	−2.42, 0.07	—	—	—	—
3c	−0.42	−1.61, 0.77	−0.94	−2.17, 0.29	−1.12	−2.29, 0.06	−1.22	−2.46, 0.03	—	—	—	—
3	−0.40	−1.59, 0.79	−0.85	−2.09, 0.38	−1.09	−2.27, 0.08	−1.11	−2.36, 0.14	—	—	—	—

[1] All values are longitudinal regression coefficients (β), estimated with generalized estimating equations ($n = 373$), with 95% CIs, and indicate the mean differences in fiber intake (in g/d) in the 24-y period between subjects in T2 and T3 compared with those in T1 of the reversed carotid or femoral DCs and CCs and the carotid E_{inc}. Model 1 was adjusted for sex, height, and time. Model 2 was adjusted as for model 1 plus total energy intake, habitual physical activity, smoking behavior, and alcohol consumption. Model 3a was adjusted as for model 2 plus mean arterial pressure. Model 3b was adjusted as for model 2 plus the skinfold-thickness ratio. Model 3c was adjusted as for model 2 plus total:HDL cholesterol ratio. Model 3 was adjusted as for model 2 plus all variables in models 3a–c. *$P < 0.05$, †$P < 0.01$, ‡$P < 0.001$. CC, compliance coefficient; DC, distensibility coefficient; E_{inc}, Young's elastic modulus; T1, lowest sex-specific tertile; T2, middle sex-specific tertile; T3, highest sex-specific tertile.

[2] Values were reversed (ie, multiplied by −1) before categorization so that higher tertiles indicate higher stiffness, in agreement with the E_{inc}.

[3] Indicates that differences remained statistically significant at the $P < 0.05$ level after correction for the 2 multiple-contrast tests (ie, T2 compared with T1 and T3 compared with T1).

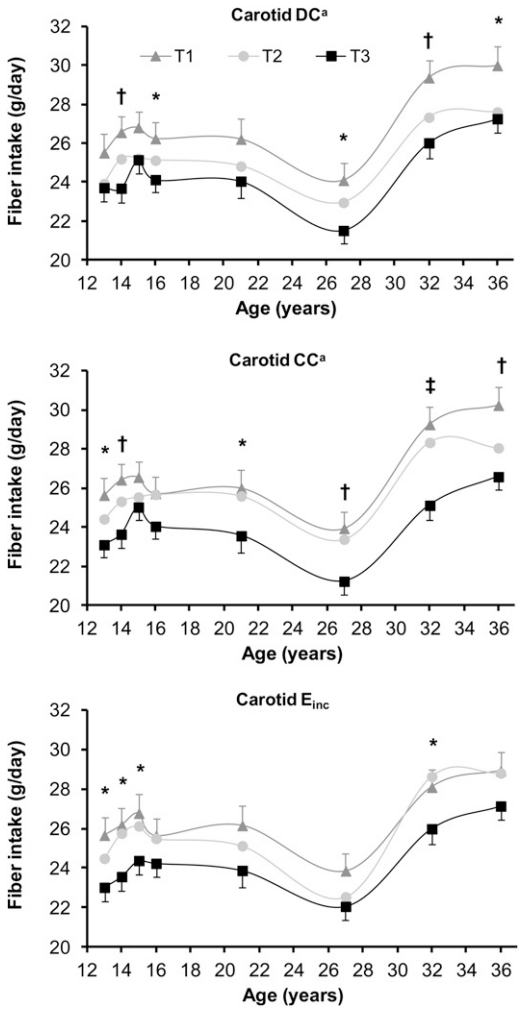

FIGURE 1. Lifetime trajectories of fiber intake throughout the 24-y study period across groups of subjects with increasing carotid stiffness at the age of 36 y (defined on the basis of sex-specific tertiles for each stiffness estimate); data were estimated with the use of generalized estimating equations and were adjusted for sex, height, and time. n = 373. $^{*}P < 0.05$, $^{\dagger}P < 0.01$, and $^{\ddagger}P < 0.001$ for comparisons between subjects in T3 and those in T1 of the DC and CC (both reversed[a]) and E_{inc}. Values are means ± SEMs. CC, compliance coefficient; DC, distensibility coefficient; E_{inc}, Young's elastic modulus; T1, lowest tertile; T2, middle tertile; T3, highest tertile.

subjects with stiffer arteries consumed fewer fiber-rich foods in the 24-y study period than did those with less stiff arteries: eg, −32.6 g fruit/d (−61.9, −3.4), −22.9 g vegetables/d (−42.6, −3.2), and −18.6 g of whole-grain products/d (−33.4, −3.8) when classified on the basis of the carotid DC (**Table 5**; model 2). These differences were explained to a great extent when additionally adjusted for fiber intake (model 3 compared with 2) but less so, if at all, when adjusted for the biological RFs (model 4 compared with 2). These biological RFs only appreciably attenuated the differences in vegetable consumption, given their stronger association with this food group (Table 4).

Indeed, mediation analyses showed that the differences in lifetime consumption of fiber-rich foods were significantly explained by fiber intake [eg, adjustments for fiber attenuated the differences in fruit by ∼65% (−21.1 g/d; 95% CI: −35.0, −8.0), in vegetables by ∼78% (−17.8 g/d; 95% CI: −29.1, −6.8), and in whole-grain products by ∼67% (−12.4 g/d; 95% CI: −20.2, −4.8)] for comparison between subjects with stiffer compared with those with less stiff arteries as defined on the basis of their carotid DC levels, and essentially similar results were obtained on the basis of CC and E_{inc} (simple mediation; *see* Supplemental Table 2 under "Supplemental data" in the online issue). Likewise, adjustment for each of the biological RFs significantly attenuated the differences in vegetable consumption but not fruit or whole-grain products. In models adjusting for all the potential mediators simultaneously, only the mediating effects of fiber intake remained largely unaffected and statistically significant (*see* Supplemental Table 2 under "Supplemental data" in the online issue; multiple mediation).

Subjects with stiffer compared with those with less stiff femoral arteries also tended to consume less fruit, vegetables, and whole-grain products in the 24-y study (*see* Supplemental Table 3 under "Supplemental data" in the online issue). However, these differences were not always statistically significant, and their magnitude was appreciably lower than that observed for the carotid artery.

Additional analyses

Additional adjustment for fatty fish intake, a major source of omega-3 (n−3) fatty acids that has been shown to lower arterial stiffness (30), did not materially affect any of the associations reported herein (data not shown). Replacing in our models the adjustment for mean arterial pressure by systolic pressure, or the adjustment for total:HDL cholesterol by total or LDL cholesterol (the latter available from the ages of 21 to 36 y only), also did not change our results (data not shown).

DISCUSSION

The major findings of this study were that *1*) adults with higher levels of arterial stiffness, mainly of the carotid artery, took consistently less fiber during the preceding 24-y covering the period from adolescence up to the age of 36 y, which suggests a favorable association between lifetime fiber intake and arterial stiffness in adulthood, and *2*) lower lifetime consumption of fruit, vegetables, and whole-grain products was similarly associated with carotid stiffness in adulthood, which could be explained, to a great extent, by the fiber portion of these foods.

A recent systematic review of intervention studies investigating the effect of changes in specific foods and/or nutrients intake on arterial stiffness concluded that omega-3 and soy isoflavone supplementation might reduce arterial stiffness (30). However, this evidence was derived from small studies, none of which investigated the role of fiber or its major dietary sources, and almost all of which were confined to older and clinical populations. Observational studies suggesting a beneficial influence of fiber on arterial stiffness are scarce too, and because these findings were derived from associations with fiber-rich foods, disentangling the specific role of fiber therein is not straightforward. For instance, a dietary pattern high in meat and alcohol and low in fruit, sweetening products, and dairy products was associated with greater aortic PWV 7.5 y later in healthy middle-aged individuals (31). In addition, a consistently high compared with low consumption of fruit and vegetables at both young and adult ages was associated with lower aortic PWV in

TABLE 4
Longitudinal associations of fiber and fiber-rich food intakes with biological risk factors[1]

	Mean arterial pressure		Skinfold-thickness ratio		Total:HDL cholesterol	
Model	β	95% CI	β	95% CI	β	95% CI
Fiber						
1	−0.066	−0.117, −0.015*	−0.061	−0.104, −0.018†	−0.092	−0.144, −0.039†
2	−0.045	−0.103, 0.012	−0.034	−0.085, 0.016	−0.047	−0.105, 0.011
Fruit						
1	0.006	−0.042, 0.054	−0.010	−0.045, 0.026	0.041	0.001, 0.081*
2	0.014	−0.034, 0.061	0.002	−0.034, 0.037	0.054	0.014, 0.094†
Vegetables						
1	−0.055	−0.095, −0.016†	−0.061	−0.099, −0.023†	−0.080	−0.128, −0.031†
2	−0.050	−0.090, −0.009*	−0.050	−0.088, −0.012†	−0.063	−0.110, −0.016†
Whole-grain products						
1	−0.027	−0.079, 0.024	−0.005	−0.044, 0.033	−0.046	−0.098, 0.007
2	−0.020	−0.073, 0.033	0.010	−0.029, 0.048	−0.025	−0.075, 0.025

[1] All values are longitudinal regression coefficients (β), estimated with generalized estimating equations (n = 373), with 95% CIs, and indicate the change in biological risk factors (in SD) per 1-SD increase in dietary fiber, fruit, vegetables, or whole grains. Model 1 was adjusted for sex, height, and time. Model 2 was adjusted as for model 1 plus total energy intake, habitual physical activity, smoking behavior, and alcohol consumption. *$P < 0.05$, †$P < 0.001$.

adulthood (15). In line with these findings, and the cardiovascular protective effects attributed to fiber (32, 33), we now show that fiber intake throughout the course of young life is inversely associated with carotid stiffness in adulthood and that the fiber content of fruit, vegetables, and whole-grain products explained, to a great extent, their similar beneficial associations with arterial stiffness.

The elastic properties of conduit arteries vary along the arterial tree because of heterogeneity in the molecular, cellular, and histologic structure of the arterial wall (1). Indeed, although central arteries contain mainly elastic fibers and relatively less collagen, this ratio is reversed in the peripheral muscular arteries, where collagens predominate (1, 34), which explains why elastic and muscular arteries may respond differently to aging, drugs, and other factors. We have therefore used ultrasonography to assess stiffness levels at different sites of the arterial tree to obtain a better understanding of the etiology of changes in arterial stiffness related to RF exposure. In this line, the current study suggests that the beneficial effects of fiber intake may act preferentially on the elastic carotid rather than on the muscular femoral or brachial arteries. The associations with carotid stiffness estimates were not confined to the DC and CC but were also observed with the E_{inc}, which suggests a higher intrinsic elasticity of the carotid artery wall among individuals who consumed more fiber. These observations also emphasize the potential clinical relevance of this study, because greater stiffness of central elastic arterial sites or segments, such as the carotid and the aorta (2, 3, 35–37), but not of peripheral arteries, have been shown to predict incident CVD. The link between arterial stiffness and incident CVD has been more often investigated and clearly established when stiffness levels of the aorta are measured by means of aortic PWV (1, 3). Although, conceptually, local and regional stiffness estimates are closely related, mismatches between carotid and aorta PWV have been reported, particularly in the presence of hypertension and/or diabetes (38). In this line, prospective studies linking carotid stiffness to incident CVD have not always led to consistent findings (2, 38). However, a recent report from the Atherosclerosis Risk in Communities Study, unique by its larger population size ($n > 10{,}000$, all free from CVD at baseline), better power with regard to incident cases, and longer duration of follow-up (>13 y) than any other such study before, showed that greater carotid stiffness estimates, as used in the current study, were significantly associated with incident stroke but not with CHD (2). Carotid stiffness may thus more closely reflect arterial damage in the cerebrovascular territories and thereby predispose to cerebrovascular disease in particular. Low fiber intake has been associated not only with higher incident CHD (10, 12) but also with stroke (11). Our current findings thus suggest that increasing fiber consumption may reduce the incidence of stroke, due, at least in part, to its beneficial effects on carotid stiffness.

Although cross-sectional (39) and prospective (40) studies have shown fiber to be favorably associated with blood pressure, body fatness, and blood lipids, the longitudinal associations between fiber intake and these RFs in the current study were not independent of the confounding effect of other lifestyle variables. Therefore, we found no evidence of a mediating role by any of these RFs in the fiber-arterial stiffness relations. This may be a result of the relatively young and healthy study population examined herein. Indeed, a meta-analysis showed that increases in fiber intake yield only modest decreases in blood pressure, which occurred mainly after the age of 40 y (41). Other fiber-related pathobiological mechanisms such as improved glucose metabolism (32), inflammation (42), and endothelial dysfunction (43)—all of which are determinants of arterial stiffness (1, 44)—may thus explain the observed associations. Longitudinal measures of these variables were not obtained in the current study, however.

Our findings may have important implications for public health. The life-course approach used to study risk exposure showed that differences in fiber intake between individuals with stiffer compared with those with less stiff arteries were already present during adolescence. This emphasizes the view that increases in fiber intake should be pursued already among young children, as recommended by current guidelines (32). Implementation of comprehensive school-based programs promoting

TABLE 5
Comparison of the mean lifetime fiber-rich food intakes between subjects with increasing levels of carotid stiffness at age 36 y[1]

	Carotid DC[2]				Carotid CC[2]				Carotid E_{inc}			
	T2 compared with T1		T3 compared with T1		T2 compared with T1		T3 compared with T1		T2 compared with T1		T3 compared with T1	
Model	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Fruit												
1	−12.8	−44.7, 19.2	−36.1	−65.2, −7.0[3,*]	−7.6	−39.8, 24.6	−43.1	−73.1, −13.1[3,†]	31.8	−0.3, 63.9	−10.4	−38.2, 17.4
2	−11.3	−43.0, 20.3	−32.6	−61.9, −3.4*	−5.9	−37.6, 25.9	−40.8	−70.4, −11.1[3,†]	32.3	1.0, 63.7*	−7.3	−35.1, 20.6
3	3.3	−26.7, 13.3	−12.3	−38.2, 13.6	1.3	−27.1, 29.7	−15.9	−40.9, 9.1	31.3	3.7, 59.0*	6.6	−18.5, 31.7
4a	−12.4	−44.1, 19.2	−35.4	−65.6, −5.3[3,*]	−6.8	−38.5, 24.9	−42.9	−72.8, −13.0[3,†]	31.6	0.3, 63.0*	−8.9	−36.8, 19.1
4b	−11.1	−42.3, 20.1	−32.6	−61.9, −3.2*	−5.8	−37.5, 25.9	−40.6	−70.6, −10.6[3,†]	32.7	1.8, 63.7*	−6.5	−34.5, 21.4
4c	−14.2	−46.1, 17.7	−36.4	−65.8, −7.0[3,*]	−9.2	−41.6, 23.2	−42.7	−72.4, −13.0[3,†]	32.0	0.4, 63.6*	−8.1	−36.4, 20.1
4	−14.0	−45.6, 17.6	−36.4	−66.7, −6.2[3,*]	−9.3	−41.5, 22.9	−42.4	−72.5, −12.3[3,†]	32.8	1.5, 64.1*	−7.1	−35.4, 21.1
Vegetables												
1	−11.3	−30.7, 8.2	−23.6	−43.3, −4.0[3,*]	0.7	−19.7, 21.1	−22.4	−41.0, −3.7[3,*]	−1.3	−20.6, 18.0	−18.9	−38.2, 0.3
2	−11.8	−31.1, 7.5	−22.9	−42.6, −3.2[3,*]	3.1	−17.2, 23.5	−21.0	−39.6, −2.4*	−1.3	−20.6, 18.0	−17.6	−36.7, 1.5
3	1.1	−14.2, 16.4	−5.6	−21.1, 10.0	9.2	−6.9, 25.4	0.1	−14.4, 14.6	−1.4	−16.7, 13.9	−5.5	−20.4, 9.4
4a	−10.4	−29.8, 8.9	−19.4	−39.5, 0.6	4.4	−16.1, 24.8	−18.2	−37.1, 0.6	−0.0	−19.5, 19.4	−14.7	−34.0, 4.6
4b	−9.9	−29.1, 9.2	−19.1	−38.5, 0.2	4.5	−15.9, 24.9	−17.6	−36.5, 1.2	0.5	−18.8, 19.9	−14.6	−33.4, 4.2
4c	−10.0	−29.5, 9.4	−20.3	−40.0, −0.5*	6.6	−14.1, 27.3	−18.7	−37.6, 0.2	−0.3	−19.7, 19.0	−15.7	−34.9, 3.5
4	−8.2	−27.5, 11.2	−15.6	−35.5, 4.4	7.8	−13.0, 28.6	−14.6	−34.0, 4.7	1.9	−17.6, 21.4	−11.7	−31.0, 7.5
Whole-grain products												
1	−15.6	−29.6, −1.6*	−20.5	−35.6, −5.3[3,†]	−10.9	−35.8, 4.0	−14.8	−30.1, 0.5	−6.7	−21.0, 7.7	−17.6	−32.1, −3.1[3,*]
2	−14.4	−27.7, −1.1*	−18.6	−33.4, −3.8[3,*]	−9.7	−24.0, 4.6	−13.8	−28.6, 1.0	−6.0	−19.9, 7.8	−15.6	−29.6, −1.6*
3	−5.4	−15.8, 5.0	−6.1	−16.8, 4.6	−4.9	−15.8, 6.0	2.0	−9.4, 13.3	−6.2	−16.7, 4.3	−6.7	−17.2, 3.7
4a	14.2	−27.6, −0.8*	−18.0	−33.4, −2.7[3,*]	−9.4	−23.8, 5.0	−13.2	−28.3, 2.0	−5.8	−19.7, 8.1	−15.0	−29.4, −0.7*
4b	−14.8	−28.2, −1.3*	−19.5	−34.8, −4.2[3,*]	−9.9	−24.3, 4.5	−14.4	−29.5, 0.7	−6.4	−20.3, 7.6	−16.1	−30.4, −1.9[3,*]
4c	−13.9	−27.1, −0.7*	−17.9	−32.8, −3.1[3,*]	−8.9	−23.3, 5.4	−13.6	−28.3, 1.1	−5.5	−19.3, 8.3	−15.6	−29.6, −1.5*
4	−14.1	−27.5, −0.8*	−16.7	−34.3, −3.0[3,*]	−9.0	−23.4, 5.5	−14.1	−29.5, 1.3	−5.8	−19.7, 8.0	−15.9	−30.5, −1.4*

[1] All values are longitudinal regression coefficients (β), estimated with generalized estimating equations ($n = 373$), with 95% CIs, and indicate the mean differences in fiber intake (in g/d) in the 24-y period between subjects in T2 and T3 compared with those in T1 of the reversed carotid or femoral DCs and CCs and the carotid E_{inc}. Model 1 was adjusted for sex, height, and time. Model 2 was adjusted as for model 1 plus total energy intake, habitual physical activity, smoking behavior, and alcohol consumption. Model 3 was adjusted as for model 2 plus fiber intake. Model 4a was adjusted as for model 2 plus mean arterial pressure. Model 4b was adjusted as for model 2 plus skinfold-thickness ratio. Model 4c was adjusted as for model 2 plus total:HDL cholesterol ratio. Model 4 was adjusted as for model 2 plus all variables in models 4a–c. $^{*}P < 0.05$, $^{\dagger}P < 0.01$. CC, compliance coefficient; DC, distensibility coefficient; E_{inc}, Young's elastic modulus; T1, lowest sex-specific tertile; T2, middle sex-specific tertile; T3, highest sex-specific tertile.

[2] Values were reversed (ie, multiplied by −1) before categorization so that higher tertiles indicate higher stiffness, in agreement with the E_{inc}.

[3] Indicates that differences remained statistically significant at the $P < 0.05$ level after correction for the 2 multiple-contrast tests (ie, T2 compared with T1 and T3 compared with T1).

consumption of fiber-rich foods, and a healthy diet in general, integrating also major determinants for success, such as parental involvement, and availability/accessibility of healthy foods (45–47), may be an effective tool to raise children's awareness and empower them for a lifelong engagement with healthy dietary habits. In addition, our data suggest that, at the population level, relatively small increases in fiber intake throughout the course of life—equivalent to the daily consumption of ~1 apple or banana or half a portion of broccoli or muesli—might translate to physiologically relevant differences in arterial stiffness in adulthood. Indeed, the absolute differences in levels of the carotid stiffness estimates between subjects grouped into the highest compared with the lowest tertiles correspond to those found for >1 decade of aging (48). Finally, although fiber, but not other biological RFs, explained a great part of the beneficial associations of fruit, vegetable, and whole-grain product intakes with arterial stiffness, other components of these foods, such as vitamins (ie, vitamins C and E and β-carotene), unsaturated fatty acids, minerals, lignans, and other phytochemicals, may favorably influence arterial stiffness and/or general cardiovascular health (49, 50). The beneficial associations observed throughout the whole longitudinal period between vegetable intake and blood pressure, central fatness, and blood lipids should also be emphasized, despite the lack of an independent mediating effect by these RFs. All of these are established cardiovascular RFs; therefore, promoting vegetable intake in particular may translate to cardiovascular health benefits beyond decreases in arterial stiffness. On the other hand, fruit intake was adversely associated with the total:HDL cholesterol ratio, but this was abolished when fruit juices [often sugar sweetened and possibly with higher glycemic indexes (51)] were removed from the fruit category (standardized longitudinal regression coefficient: 0.009; 95% CI: −0.033, 0.052). Noteworthy, the associations with arterial stiffness remained qualitatively unchanged (data not shown). All together, our findings suggest that primary prevention efforts focusing on increased intakes of fresh/low–glycemic index fruit, vegetables, and whole-grain products may translate to beneficial arterial and cardiovascular health in general.

Some limitations of our study need to be addressed. First, measurement of dietary habits with the use of questionnaires is subject to recall and misclassification bias (52). Likely, any such bias was largely nondifferential because, throughout the study period, participants were unaware of their stiffness levels at age 36 y. However, if any differential misclassification has occurred, this most likely derived from the overreporting of healthier dietary habits by those with unhealthier lifestyles (52). Either way, effect sizes may have been underestimated. Second, although in our analyses ascertainment of the "cause" (ie, dietary intake from adolescence to adult age) preceded that of the "consequence" (ie, arterial stiffness), definite conclusions with regard to causality cannot be inferred given the observational study design. Third, although very unlikely, we cannot exclude the possibility of reverse causation because arterial stiffness was measured at the age of 36 y only. Fourth, we were not able to distinguish between soluble and insoluble fibers; further (experimental) studies may be needed to clarify any potential differential associations of these on arterial stiffness. Last, our findings were obtained in a young, healthy, and generally white cohort and should thus be interpreted with caution when extrapolated to elderly, high-risk populations and other ethnicities.

In conclusion, we showed that a lower intake of dietary fiber throughout the course of young life (ie, from adolescence up to adulthood) is associated with higher carotid stiffness in adulthood. Promoting the consumption of fiber-rich foods at a young age may offer an important means to prevent accelerated arterial stiffening and related sequelae in later in life.

The authors' responsibilities were as follows—RJJvdL, CDAS, MHP, JWRT, and IF: designed the research; RJJvdL, BCTvB, SJtV, JWRT, and IF: conducted the research; RJJvdL and IF: performed the statistical analyses; and RJJvdL, CDAS, and IF: wrote the manuscript and had primary responsibility for the final content. All authors critically read and approved the final manuscript. None of the authors declared a conflict of interest. None of the sponsors had any role in the design and conduct of the study; in the collection, management, analysis, and interpretation of data; or in the preparation, review, or approval of the manuscript.

REFERENCES

1. Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D, Pannier B, Vlachopoulos C, Wilkinson I, Struijker-Boudier H. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur Heart J 2006;27:2588–605.
2. Yang EY, Chambless L, Sharrett AR, Virani SS, Liu X, Tang Z, Boerwinkle E, Ballantyne CM, Nambi V. Carotid arterial wall characteristics are associated with incident ischemic stroke but not coronary heart disease in the Atherosclerosis Risk in Communities (ARIC) Study. Stroke 2012;43:103–8.
3. Vlachopoulos C, Aznaouridis K, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis. J Am Coll Cardiol 2010;55:1318–27.
4. Ferreira I, van de Laar RJ, Prins MH, Twisk JW, Stehouwer CD. Carotid stiffness in young adults: a life-course approach of its early determinants. The Amsterdam Growth and Health Longitudinal Study. Hypertension 2012;59:54–61.
5. van de Laar RJ, Ferreira I, van Mechelen W, Prins MH, Twisk JW, Stehouwer CD. Lifetime vigorous but not light-to-moderate habitual physical activity impacts favorably on carotid stiffness in young adults: the Amsterdam Growth and Health Longitudinal Study. Hypertension 2010;55:33–9.
6. van de Laar RJ, Ferreira I, van Mechelen W, Prins MH, Twisk JW, Stehouwer CD. Habitual physical activity and peripheral arterial compliance in young adults: the Amsterdam Growth and Health Longitudinal Study. Am J Hypertens 2011;24:200–8.
7. Juonala M, Järvisalo MJ, Mäki-Torkko N, Kähönen M, Viikari JS, Raitakari OT. Risk factors identified in childhood and decreased carotid artery elasticity in adulthood: the Cardiovascular Risk in Young Finns Study. Circulation 2005;112:1486–93.
8. Li S, Chen W, Srinivasan SR, Berenson GS. Childhood blood pressure as a predictor of arterial stiffness in young adults: the Bogalusa Heart Study. Hypertension 2004;43:541–6.
9. Kelder SH, Perry CL, Klepp KI, Lytle LL. Longitudinal tracking of adolescent smoking, physical activity, and food choice behaviors. Am J Public Health 1994;84:1121–6.
10. Bazzano LA, He J, Ogden LG, Loria CM, Whelton PK. Dietary fiber intake and reduced risk of coronary heart disease in US men and women: the National Health and Nutrition Examination Survey I Epidemiologic Follow-up Study. Arch Intern Med 2003;163:1897–904.
11. Mozaffarian D, Kumanyika SK, Lemaitre RN, Olson JL, Burke GL, Siscovick DS. Cereal, fruit, and vegetable fiber intake and the risk of cardiovascular disease in elderly individuals. JAMA 2003;289:1659–66.
12. Pereira MA, O'Reilly E, Augustsson K, Fraser GE, Goldbourt U, Heitmann BL, Hallmans G, Knekt P, Liu S, Pietinen P, et al. Dietary fiber and risk of coronary heart disease: a pooled analysis of cohort studies. Arch Intern Med 2004;164:370–6.
13. Park Y, Subar AF, Hollenbeck A, Schatzkin A. Dietary fiber intake and mortality in the NIH-AARP diet and health study. Arch Intern Med 2011;171:1061–8.
14. Lichtenstein AH, Appel LJ, Brands M, Carnethon M, Daniels S, Franch HA, Franklin B, Kris-Etherton P, Harris WS, Howard B, et al. Diet and

lifestyle recommendations revision 2006: a scientific statement from the American Heart Association Nutrition Committee. Circulation 2006;114:82–96.
15. Aatola H, Koivistoinen T, Hutri-Kähönen N, Juonala M, Mikkilä V, Lehtimäki T, Viikari JS, Raitakari OT, Kähönen M. Lifetime fruit and vegetable consumption and arterial pulse wave velocity in adulthood: the Cardiovascular Risk in Young Finns Study. Circulation 2010;122: 2521–8.
16. Kemper HC. Amsterdam Growth and Health Longitudinal Study (AGAHLS). A 23-year follow-up from teenager to adult about lifestyle and health. Basel, Switzerland: Karger, 2004.
17. Brands PJ, Hoeks AP, Willigers J, Willekes C, Reneman RS. An integrated system for the non-invasive assessment of vessel wall and hemodynamic properties of large arteries by means of ultrasound. Eur J Ultrasound 1999;9:257–66.
18. Reneman RS, Hoeks AP. Noninvasive vascular ultrasound: an asset in vascular medicine. Cardiovasc Res 2000;45:27–35.
19. Van Bortel LM, Balkestein EJ, van der Heijden-Spek JJ, Vanmolkot FH, Staessen JA, Kragten JA, Vredeveld JW, Safar ME, Struijker Boudier HA, Hoeks AP. Non-invasive assessment of local arterial pulse pressure: comparison of applanation tonometry and echo-tracking. J Hypertens 2001;19:1037–44.
20. Beal VA. The nutritional history in longitudinal research. J Am Diet Assoc 1967;51:426–32.
21. Marr JW. Individual dietary surveys: purposes and methods. World Rev Nutr Diet 1971;13:105–64.
22. te Velde SJ, Twisk JW, Brug J. Tracking of fruit and vegetable consumption from adolescence into adulthood and its longitudinal association with overweight. Br J Nutr 2007;98:431–8.
23. Bakker I, Twisk JW, van Mechelen W, Mensink GB, Kemper HC. Computerization of a dietary history interview in a running cohort; evaluation within the Amsterdam Growth and Health Longitudinal Study. Eur J Clin Nutr 2003;57:394–404.
24. Bertheke Post G, de Vente W, Kemper HC, Twisk JW. Longitudinal trends in and tracking of energy and nutrient intake over 20 years in a Dutch cohort of men and women between 13 and 33 years of age: the Amsterdam growth and health longitudinal study. Br J Nutr 2001;85: 375–85.
25. NEVO Tabel 1996 (Dutch food composition table 1996.) The Hague, Netherlands: Voorlichtingsbureau Voor de Voeding, 1996.
26. Ferreira I, Twisk JW, van Mechelen W, Kemper HC, Stehouwer CD. Development of fatness, fitness, and lifestyle from adolescence to the age of 36 years: determinants of the metabolic syndrome in young adults: the Amsterdam Growth and Health Longitudinal Study. Arch Intern Med 2005;165:42–8.
27. Twisk JWR. Applied longitudinal data analysis for epidemiolgy: a practical guide. Cambridge, United Kingdom: Cambridge University Press, 2003.
28. Lockwood CM, DeFrancesco CA, Elliot DL, Beresford SA, Toobert DJ. Mediation analyses: applications in nutrition research and reading the literature. J Am Diet Assoc 2010;110:753–62.
29. Tofighi D, Mackinnon DP. RMediation: an R package for mediation analysis confidence intervals. Behav Res Methods 2011;43:692–700.
30. Pase MP, Grima NA, Sarris J. The effects of dietary and nutrient interventions on arterial stiffness: a systematic review. Am J Clin Nutr 2011;93:446–54.
31. Kesse-Guyot E, Vergnaud AC, Fezeu L, Zureik M, Blacher J, Péneau S, Hercberg S, Galan P, Czernichow S. Associations between dietary patterns and arterial stiffness, carotid artery intima-media thickness and atherosclerosis. Eur J Cardiovasc Prev Rehabil 2010;17:718–24.
32. Slavin JL. Position of the American Dietetic Association: health implications of dietary fiber. J Am Diet Assoc 2008;108:1716–31.
33. Anderson JW, Baird P, Davis RH Jr, Ferreri S, Knudtson M, Koraym A, Waters V, Williams CL. Health benefits of dietary fiber. Nutr Rev 2009; 67:188–205.
34. Safar ME, Levy BI, Struijker-Boudier H. Current perspectives on arterial stiffness and pulse pressure in hypertension and cardiovascular diseases. Circulation 2003;107:2864–9.
35. Barenbrock M, Kosch M, Joster E, Kisters K, Rahn KH, Hausberg M. Reduced arterial distensibility is a predictor of cardiovascular disease in patients after renal transplantation. J Hypertens 2002;20:79–84.
36. Blacher J, Guerin AP, Pannier B, Marchais SJ, London GM. Arterial calcifications, arterial stiffness, and cardiovascular risk in end-stage renal disease. Hypertension 2001;38:938–42.
37. Dijk JM, Algra A, van der Graaf Y, Grobbee DE, Bots ML. Carotid stiffness and the risk of new vascular events in patients with manifest cardiovascular disease. The SMART study. Eur Heart J 2005;26:1213–20.
38. Paini A, Boutouyrie P, Calvet D, Tropeano A-I, Laloux B, Laurent S. Carotid and aortic stiffness: determinants of discrepancies. Hypertension 2006;47:371–6.
39. Lairon D, Arnault N, Bertrais S, Planells R, Clero E, Hercberg S, Boutron-Ruault MC. Dietary fiber intake and risk factors for cardiovascular disease in French adults. Am J Clin Nutr 2005;82:1185–94.
40. Ludwig DS, Pereira MA, Kroenke CH, Hilner JE, Van Horn L, Slattery ML, Jacobs DR Jr. Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. JAMA 1999;282:1539–46.
41. Streppel MT, Arends LR, van 't Veer P, Grobbee DE, Geleijnse JM. Dietary fiber and blood pressure: a meta-analysis of randomized placebo-controlled trials. Arch Intern Med 2005;165:150–6.
42. King DE, Egan BM, Woolson RF, Mainous AG 3rd, Al-Solaiman Y, Jesri A. Effect of a high-fiber diet vs a fiber-supplemented diet on C-reactive protein level. Arch Intern Med 2007;167:502–6.
43. Brock DW, Davis CK, Irving BA, Rodriguez J, Barrett EJ, Weltman A, Taylor AG, Gaesser GA. A high-carbohydrate, high-fiber meal improves endothelial function in adults with the metabolic syndrome. Diabetes Care 2006;29:2313–5.
44. Stehouwer CD, Henry RM, Ferreira I. Arterial stiffness in diabetes and the metabolic syndrome: a pathway to cardiovascular disease. Diabetologia 2008;51:527–39.
45. Briggs M, Mueller CG, Fleischhacker S. Position of the American Dietetic Association, School Nutrition Association, and Society for Nutrition Education: comprehensive school nutrition services. J Am Diet Assoc 2010;110:1738–49.
46. Knai C, Pomerleau J, Lock K, McKee M. Getting children to eat more fruit and vegetables: a systematic review. Prev Med 2006;42:85–95.
47. O'dea JA. Why do kids eat healthful food? Perceived benefits of and barriers to healthful eating and physical activity among children and adolescents. J Am Diet Assoc 2003;103:497–501.
48. Vermeersch SJ, Rietzschel ER, De Buyzere ML, De Bacquer D, De Backer G, Van Bortel LM, Gillebert TC, Verdonck PR, Segers P. Age and gender related patterns in carotid-femoral PWV and carotid and femoral stiffness in a large healthy, middle-aged population. J Hypertens 2008;26:1411–9.
49. Ness AR, Powles JW. Fruit and vegetables, and cardiovascular disease: a review. Int J Epidemiol 1997;26:1–13.
50. Slavin J. Whole grains and human health. Nutr Res Rev 2004;17: 99–110.
51. Jenkins DJ, Srichaikul K, Kendall CW, Sievenpiper JL, Abdulnour S, Mirrahimi A, Meneses C, Nishi S, He X, Lee S, et al. The relation of low glycaemic index fruit consumption to glycaemic control and risk factors for coronary heart disease in type 2 diabetes. Diabetologia 2011;54:271–9.
52. Macdiarmid J, Blundell J. Assessing dietary intake: who, what and why of under-reporting. Nutr Res Rev 1998;11:231–53.