Individual and Neighborhood Deprivation and Carotid Stiffness

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The Paris Prospective Study III

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Abstract—Large artery stiffness is an index of vascular aging associated with cardiovascular mortality. Whereas traditional risk factors for arterial stiffness are known, the contribution of socioeconomic factors is less reported. We sought to determine the relationship between arterial stiffness and socioeconomic deprivation (at the individual and neighborhood levels) in healthy males and females. In 7803 adults, carotid stiffness was determined by high-precision carotid echotracking. Individual deprivation data included education, living alone, occupation, and Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers score. Neighborhood deprivation was determined from commune level data (smallest administrative subdivision) available from French National Institute of Statistics and Economic Studies (2011) using principal component analysis. The separate and combined associations between individual and neighborhood deprivation (main exposures) and carotid stiffness (outcome) were quantified using linear and multilevel model adjusted for traditional risk factors. Analyses were conducted separately in males and females. Individual deprivation (lower education and occupation in males and living alone and higher Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers in both populations) was adversely related to carotid stiffness, independently of potential confounders ($P<0.05$). Neighborhood deprivation was adversely related to carotid stiffness in males ($P<0.05$), but not in females. Socioeconomic deprivation, both at individual and, to a lesser extent, neighborhood level are associated with carotid stiffness in males. Only individual deprivation is associated with carotid stiffness in females. **(*Hypertension*. 2019;73:1185-1194. DOI: 10.1161/HYPERTENSIONAHA.118.12186.)** • **Online Data Supplement**

Key Words: aorta ■ blood pressure ■ occupation ■ risk factors ■ socioeconomic factors

Large artery stiffness can be used as an index of early vascular aging[1] and is an independent predictor of coronary events, stroke, and all-cause and cardiovascular mortality.[2–4] An increase in stiffness of the carotid artery, in particular, is associated with incident stroke[5] whereas lower carotid distensibility coefficient is associated with incident cardiovascular disease (CVD) events and all-cause mortality.[6] Furthermore, an individual participant data meta-analysis showed that carotid stiffness has a predictive value independent of age and blood pressure (BP).[5] Hence, addressing modifiable determinants of arterial (carotid) stiffness carry public health implications for the early prevention of CVD. Although traditional risk factors (age and mean BP) explain up to 50% of arterial stiffness variance,[7] there is still a large proportion unknown, which may be explained by nonconventional CVD determinants. For example, the contribution of socioeconomic factors on arterial stiffness is little studied. Low socioeconomic groups are subjected to increased risk of CVD, which may be attributed to a combination of biological, behavioral, and psychosocial risk factors that cluster together and are more prevalent in disadvantaged, or deprived, areas.[8,9] Markers of socioeconomic level at the individual level, or individual deprivation (ID), such as personal income, education, and occupation have been linked to increased CVD risk[10]; however, their contribution to arterial stiffness has not been thoroughly explored.[11–14]

The socioeconomic environment of one's neighborhood has also been associated with increased risk of coronary heart disease,[15] heart failure,[16] and mortality,[17] as well as higher carotid intima-media thickness and systolic BP.[18,19] Importantly, in these studies, the relationship between neighborhood deprivation (ND) and health outcomes appears to be independent of ID factors, suggesting that the attributes of one's neighborhood may be important for health, irrespective of the level of ID. However, to our knowledge, the association between ND

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and carotid stiffness has never been reported. In addition, the relative associations between ID and ND with carotid stiffness are unknown. Furthermore, females are overrepresented among those living in poverty and are disproportionally affected by disparities in the distribution of wealth, income, and access to healthcare resources.[20] Thus it is possible that ID and ND may be differentially associated with carotid stiffness in males compared with females. Therefore, the aim of this study was to examine the association between ID and ND and carotid stiffness. We decided a priori to examine the associations separately in males and females.

Methods

Data are available on request subject to approval by the PPS3 (Paris Prospective Study 3) scientific committee.

Study Participants and Overview

This study was a cross-sectional analysis of the PPS3—an ongoing observational prospective study which has been described in detail elsewhere.[21,22] Briefly, 10 157 healthy males and females aged 50 to 75 years were recruited from a large preventative medical center, the Centre d'Investigations Preventives et Cliniques (IPC center) in Paris (France) between June 2008 and May 2012. At study recruitment, participants underwent a standard clinical examination, during which resting high-resolution carotid echo-tracking was performed to measure arterial stiffness parameters in a quiet and temperature controlled room (22+1°). Participants completed self-administered questionnaires to derive information on lifestyle (ie, physical activity using the validated Baecke questionnaire,[23] diet, smoking, and alcohol), personal and family medical history, and socioeconomic (education and occupation) factors. Fasting blood samples were taken to assess for standard blood biomarkers. BP was measured 3× using a validated digital electronic BP monitor (A & D TM-2541; A&D Company, Tokyo, Japan) after 10 minutes of supine rest. The mean of the last 2 measurements was calculated and used in the analysis. Participants provided informed written consent, and the study protocol was approved by the Ethics Committee of the Cochin Hospital (Paris). The study is registered in the international trial registry (http://www.clinicaltrials.gov. Unique identifier: NCT00741728).

Markers of ID

Education was defined as no education, secondary education, and tertiary education or higher. Occupation was categorized by decreasing categories as high (eg. managers), medium (eg. clerks or first-line supervisors), low (eg. blue-collar workers), and no professional activity or unemployed. All participants were categorized as living alone or not. We also assessed ID using a composite index, the Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers (EPICES) score that is widely used in preventive care centers in France.[24] EPICES is the combination of 11 measures of ID, including family structure, living conditions, employment, social support, financial difficulties, and leisure activities. A higher score indicates worse ID. EPICES has been validated in a sample of nearly 200 000 individuals.[24]

Neighborhood Deprivation

We used commune level data (2011) available from French National Institute of Statistics and Economic Studies (INSEE) to determine ND. ND was determined following a similar approach as recently applied in the Three-City Study.[25] Using principal component analysis, we defined ND for each commune using 10 ND measures: proportion of blue-collar workers, proportion of residents without secondary education, proportion of households rented, proportion of households without a car, proportion of single parents, proportion of people aged ≥60 years, Gini index (a maker of income inequality), adult unemployment rate, household overcrowding index, and median household net taxable income per consumption unit. The definition for each measure is provided in the online-only Data Supplement.

The first axis in the principal component analysis summarized the best composition data of the neighborhoods (53.53% variance explained, Figure S1 in the online-only Data Supplement). The position of the commune on this axis defined the degree of ND. We then categorized communes based on their level of ND into tertiles from least deprived to most deprived communes.

Carotid Stiffness

Measurements were performed at the right common carotid artery, 1 cm proximal from the carotid bulb bifurcation using the ArtLab (Esaote) high-resolution echo-tracking technology after 10 minutes of rest in a supine position. Carotid stiffness (m/s) was derived from distensibility coefficient using the Bramwell and Hill equation. Structural parameters including internal and external diameters (*Di* and *De*) were measured to allow for calculation of other arterial stiffness parameters for comparison with carotid stiffness. Incremental elastic modulus (*E*inc) was calculated as $E\text{inc}=[3(1+Di^2/(De-Di)^2)]/DC$. The distensibility coefficient was calculated as radial wall strain/PP, where radial wall strain=$(Ds-Dd)/Dd$ and PP (*D* for diameter, *s* for systole, *d* for diastole, PP for pulse pressure) was carotid pulse pressure obtained by integration of the carotid distension waveform with calibration using brachial BPs. Higher stiffness and *E*inc and lower distensibility coefficient indicated worse arterial parameters.

Statistical Analysis

Descriptive data are expressed as mean±SD for continuous variables and n (%) for categorical variables unless otherwise stated. Data that were not normally distributed (fasting glucose, triglycerides, *E*inc) were log transformed. EPICES was also not normally distributed and could not be normalized by a log transformation, and therefore, sex-specific quartiles of EPICES were created. Comparisons between ID quartiles or ND tertiles and *P* value for trend were obtained using ANOVA for continuous data and Cochran-Armitage test for categorical data.

Sex-stratified analysis was decided a priori based on existing literature data. This was further supported by the presence of a significant interaction between sex, ND tertiles, and carotid stiffness (*P* for interaction =0.001). Linear regression analyses were performed to quantify the associations between ID (education, occupation, living alone, and EPICES; primary exposure) and carotid stiffness. ID factors were first investigated in separate analysis and then after mutual adjustment. Models were adjusted for variables known or suspected to contribute the variance of arterial stiffness from the literature and included age, mean BP, body mass index, fasting glucose, high-density lipoprotein, triglycerides, heart rate, history of CVD, smoking, alcohol, and physical activity. The linearity assumption of the association between EPICES score and carotid stiffness was ensured in males and females respectively by comparing Akaike information criterion values of linear model (Akaike information criterion=16392.2 and 10681.9) versus models with quadratic (Akaike information criterion=16410.4 and 10698.0) or cubic (Akaike information criterion=16434.6 and 10728.3) terms on EPICES. Multilevel analysis[26] was performed to assess the associations between ND (coprimary exposure) and carotid stiffness, using a random intercept model (random effect=commune). For consistency across the analyses, no random slope was included in the models. Analyses were adjusted for the same covariates used for the investigation of ID. To disentangle the association with ID and ND, we then adjusted the models of ND by adding ID factors separately. Finally, in a sensitivity analysis, we examined the association between ND and carotid stiffness in non-ID deprived participants (ie, those in quartile 1 based on EPICES). All analyses were 2-sided and $P<0.05$ was considered statistically significant. All data were analysed using SAS 9.4 (Statistical Analysis System, Cary, NC).

Results

Participant Characteristics

Of the initial 10 157 participants recruited into the PPS3 study, 2354 had missing data on at the commune level (n=285), arterial

stiffness parameters (n=1264; due to technical issues) or covariates (n=805) leaving a final study population of 7803 participants (Figure S2). The characteristics of those excluded from the current analysis are presented in Table S1. Those who were excluded from the analysis were older, of greater body mass index, were more likely to smoke, had lower education level, and were more likely to be taking medication compared with those that were included. The characteristics of the included participants by ID (EPICES) are shown in Tables 1 and 2 and by ND are shown in Tables 3 and 4. Male participants had a greater body mass index, were more likely to smoke and consume alcohol, obtained higher educational level, and had a higher occupational level. They were less likely to live alone and have depressive symptoms. The overall participant characteristics are shown in Table S2. Four hundred and seventy communes were involved in the analysis. The median number of subjects and interquartile range per commune was 7 (3–7) for the overall population, 3 (1–8) for females, and 5 (2–12) for males.

Distribution of Carotid Stiffness by Level of ID

Figure [A] displays the distribution of carotid stiffness by quartiles of ID (EPICES score). There was a significant trend for worsening carotid stiffness across quartiles of ID in both males (P<0.001 for all) and females (<0.05 for all), adjusted

Table 1. Distribution of Participant Characteristics According to Quartile of Individual Deprivation (EPICES Score) in Male (n=4807) Subjects

	Male				
Participant Characteristics	Quartile 1 (n=1375)	Quartile 2 (n=1080)	Quartile 3 (n=1184)	Quartile 4 (n=1168)	*P* for Trend
Age, y	59±6*	59±6†	59±6†	58±6†	0.0002
Body mass index, kg/m^2	25.42±2.94†	25.75±3.13†	25.77±3.21†	26.00±3.46†	<0.0001
Current smoker, n (%)	153 (11)	150 (14)	182 (15)	264 (23) †	<0.0001
Consume alcohol, n (%)	1303 (95) †	1009 (93)†	1067 (90) †	959 (82)	<0.0001
History of cardiovascular disease, n (%)	20 (1)	20 (2)	23 (2)	41 (4)	<0.0001
EPICES score	0.00±0.00	7.39±0.80*	18.16±4.65	44.86±13.85	<0.0001
Education, n (%)					
No education	24 (2)	28 (3)	72 (6)	148 (13)	<0.0001
Secondary education	204 (15) *	209 (19) *	279 (24) †	358 (31)	<0.0001
Tertiary education	1147 (83) *	843 (78) *	833 (70) †	662 (57)	<0.0001
Professional occupation category, n (%)‡					
High	916 (67)†	632 (59)†	550 (47)†	340 (30)†	<0.0001
Medium	338 (25)†	334 (31)†	414 (36)†	405 (36)†	<0.0001
Low	34 (3)†	37 (3)*	105 (9)†	174 (16)†	<0.0001
Inactive	7 (1)†	4 (0)†	9 (1)†	19 (2)*	0.003
Unemployed	67 (5)	65 (6)*	83 (7)*	184 (16)*	<0.0001
Live alone, n (%)	0 (0)	181 (17)†	302 (26) †	387 (33)†	<0.0001
Depressive symptoms, n (%)	15 (1)†	24 (2)†	37 (3) †	77 (7)†	<0.0001
Total physical activity score	7.4±1.4†	6.9±1.5†	7.0±1.6†	6.8±1.7†	<0.0001
Systolic blood pressure, mm Hg	132±15†	133±15†	133±15*	133±16	0.017
Resting heart rate, bpm	60±8†	61±9*	62±9*	62±10†	<0.0001
BP lowering medication, n (%)	177 (13)	153 (14)	189 (16)	180 (15) *	0.033
Lipid-lowering medication, n (%)	169 (14)	145 (15)	141 (14)	127 (12)	0.205
Glucose-lowering medication, n (%)	24 (2)	26 (2)*	33 (3) *	40 (3)	0.008
Fasting glucose, mg/dL§	4.6±0.1†	4.6±0.1†	4.6±0.1†	4.6±0.1†	0.052
Total cholesterol, mg/dL	217.3±33.0†	216.4±34.1†	214.7±36.5†	214.3±37.5†	0.025
High-density lipoprotein, mg/dL	54.6±12.1†	53.8±11.9†	53.6±12.9†	50.4±12.9†	<0.0001
Triglycerides, mg/dL§	4.6±0.4†	4.6±0.4†	4.6±0.4†	4.7±0.5†	<0.0001

Data are mean±SD, unless otherwise stated. BP indicates blood pressure; and EPICES, Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers.
*P value for comparison with females of the same quartile <0.05.
†P value for comparison with females of the same quartile <0.0001.
‡Data missing in n=183.
§Data were log transformed. Quartile 1 is least deprived, and quartile 4 is most deprived.

Table 2. Distribution of Participant Characteristics According to Quartile of Individual Deprivation (EPICES Score) in Female (n=2996) Subjects

Participant Characteristics	Female				
	Quartile 1 (n=673)	Quartile 2 (n=879)	Quartile 3 (n=694)	Quartile 4 (n=750)	*P* for Trend
Age, y	60±6	61±6	61±6	60±6	0.32
Body mass index, kg/m^2	23.32±3.37	23.90±3.80	24.08±4.06	24.86±4.46	<0.0001
Current smoker, n (%)	59 (9)	121 (14)	86 (13)	102 (14)	0.002
Consume alcohol, n (%)	595 (88)	755 (86)	574 (83)	587 (78)	<0.0001
History of cardiovascular disease, n (%)	7 (1)	11 (1)	14 (2)	15 (2)	0.046
EPICES score	0.00±0.00	9.17±2.85	21.15±4.61	46.58±12.87	<0.0001
Education, n (%)					
No education	14 (2)	39 (4)	47 (7)	85 (11)	<0.0001
Secondary education	133 (20)	246 (28)	234 (34)	257 (34)	<0.0001
Tertiary education	526 (78)	594 (68)	413 (60)	408 (54)	<0.0001
Professional occupation category, n (%)*					
High	235 (36)	278 (32)	192 (29)	123 (17)	<0.0001
Medium	299 (46)	474 (55)	388 (58)	441 (61)	<0.0001
Low	2 (0)	11 (1)	24 (4)	48 (7)	<0.0001
Inactive	81 (13)	63 (7)	24 (4)	31 (4)	<0.0001
Unemployed	31 (5)	31 (4)	44 (7)	83 (11)	<0.0001
Live alone, n (%)	0 (0)	315 (36)	389 (56)	458 (61)	<0.0001
Depressive symptoms, n (%)	26 (4)	50 (6)	68 (10)	120 (16)	<0.0001
Total physical activity score	6.8±1.4	6.5±1.5	6.5±1.5	6.5±1.7	<0.0001
Systolic blood pressure, mm Hg	126±17	127±16	130±18	130±18	<0.0001
Resting heart rate, bpm	62±9	63±8	63±9	63±8	0.0003
BP-lowering medication, n (%)	82 (12)	134 (15)	113 (16)	146 (19)	0.0002
Lipid-lowering medication, n (%)	81 (13)	103 (13)	76 (12)	95 (14)	0.78
Glucose-lowering medication, n (%)	7 (1)	11 (1)	8 (1)	18 (2)	0.042
Fasting glucose, mg/dL†	4.6±0.1	4.6±0.1	4.6±01	4.6±0.1	0.39
Total cholesterol, mg/dL	230.1±35.9	229.3±33	228.1±36.1	228.9±37.9	0.33
High-density lipoprotein, mg/dL	69.4±15.3	68.0±14.8	67.7±14.9	64.2±14.9	<0.0001
Triglycerides, mg/dL†	4.4±0.3	4.4±0.4	4.4±0.4	4.5±0.4	<0.0001

Data are mean±SD, unless otherwise stated. BP indicates blood pressure; and EPICES, Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers.
*Data missing in n=183.
†Data were log transformed. Quartile 1 is least deprived, and quartile 4 is most deprived.

for age and mean BP. Figure S3A and S3B display the distribution *E*inc and distensibility by quartiles of ID.

Association Between ID Measures and Carotid Stiffness

The separate associations between ID measures and carotid stiffness are shown in Table 5. After adjustment for potential confounders, living alone was associated with 0.12 m/s increases in carotid stiffness in males and 0.10 m/s increase in stiffness in females, and EPICES (per quartile increase) was associated with 0.08 and 0.06 m/s increase in stiffness in males and females, respectively. In males, low education and occupation level were associated with 0.13 and 0.05 m/s increases in carotid stiffness respectively. When all ID markers were included in the same model (Table S3), lower education and higher EPICES score were related to carotid stiffness in males, but there were no associations in females. Table S4 displays the separate associations between ID and *E*inc and distensibility coefficient in males and females, and Table S5 displays the separate associations between ID markers and arterial stiffness in all participants.

Distribution of Carotid Stiffness by Level of ND

Figure [B] displays the distribution of carotid stiffness by tertiles of ND. In males, there was a significant trend for worsening stiffness across tertiles of ND (*P*=0.0004), and in females,

Table 3. Distribution of Participant Characteristics According to Tertile of Neighborhood Deprivation in Male (n=4807) Subjects

	Male			
Participant Characteristics	Tertile 1 (n=1604)	Tertile 2 (n=1601)	Tertile 3 (n=1602)	*P* for Trend
Age, y	59±6*	59±6*	58±6*	<0.0001
Body mass index, kg/m^2	25.55±3.11*	25.67±3.28*	25.94±3.15*	0.001
Current smoker, n (%)	215 (13)†	253 (16)	281 (18)†	0.002
Consume alcohol, n (%)	1489 (93)*	1471 (92)*	1378 (86)*	<0.0001
History of cardiovascular disease, n (%)	34 (2)	29 (2)	41 (3)	0.39
Neighborhood deprivation	−2.4±0.9†	−0.3±4	2.7±1.6	<0.0001
Education, n (%)				
No education	55 (3)	75 (5)	142 (9)	<0.0001
Secondary education	251 (16)*	343 (21)†	456 (28)*	<0.0001
Tertiary education	1298 (81)*	1183 (74)†	1004 (63)*	<0.0001
Professional occupation category, n (%)‡				
High	958 (61)*	846 (54)*	634 (41)*	<0.0001
Medium	437 (28)*	502 (32)*	552 (35)*	<0.0001
Low	67 (4)†	89 (6)†	194 (12)*	<0.0001
Inactive	11 (1)*	11 (1) *	17 (1)†	0.24
Unemployed	107 (7)	124 (8)	168 (11)†	<0.0001
Live alone, n (%)	219 (14)	294 (18)*	357 (22)*	<0.0001
Depressive symptoms, n (%)	42 (3)*	45 (3)*	66 (4)*	0.016
Total physical activity score	6.99±1.52*	7.04±1.55*	7.10±1.65*	0.064
Systolic blood pressure, mm Hg	133±15*	132±15*	133±16*	0.96
Resting heart rate, bpm	61±9*	61±9*	62±9†	<0.0001
BP lowering medication, n (%)	219 (14)	221 (14)	259 (16)	0.043
Lipid-lowering medication, n (%)	190 (13)	201 (14)	191 (14)	0.91
Glucose-lowering medication, n (%)	34 (2)†	37 (2)†	52 (3)	0.044
Fasting glucose, mg/dL§	4.6±0.1*	4.6±0.1*	4.6±0.1*	0.32
Total cholesterol, mg/dL	216.5±34.5*	215.6±35.3*	215.0±36.1*	0.21
High-density lipoprotein, mg/dL	54.1±12.9*	53.1±12.5*	52.3±12.3*	<0.0001
Triglycerides, mg/dL§	4.6±0.4*	4.6±0.4*	4.6±0.4*	0.066

Data are mean±SD, unless otherwise stated. BP, blood pressure.
**P* value for comparison with females of the same tertile <0.0001.
†*P* value for comparison with females of the same tertile <0.05.
‡Data missing in n=183.
§Data were log transformed. Quartile 1 is least deprived, and quartile 4 is most deprived.

carotid stiffness also tended to worsen across tertiles, however, nonsignificantly (*P*>0.05 for all). Figure S3C and S3D displays the distribution *E*inc and distensibility by tertiles of ND.

Association Between ND and Carotid Stiffness

Table 6 shows the multivariable associations between tertiles of ND and carotid stiffness. In males, the third as compared to the first tertile of ND was associated with 0.12 m/s (95% CI, 0.03–0.22) increase in carotid stiffness independently of potential confounders (model 1, *P* value for main effect=0.024), whereas no association was observed in women. When ID (ie, EPICES) was added into the model (model 2) in males, the third as compared to the first tertile of ND was associated with 0.10 m/s (95% CI, 0.008–0.019) nonsignificant increase in carotid stiffness (*P* value for main effect =0.11). In this model, higher EPICES was associated with 0.08 m/s (95% CI, 0.05–0.11) increase in carotid stiffness in males (*P* value <0.0001). Table S6 displays the results for distensibility coefficient and *E*inc. When other ID markers, including education, living alone, and occupation, were alternatively added to the model including ND (Table S7), ND remained significantly and systematically related to carotid stiffness in males. In females, ND was not related to carotid stiffness. Table S8 displays the associations between ND markers and arterial

Table 4. Distribution of Participant Characteristics According to Tertile of Neighborhood Deprivation in Female (n=2996) Subjects

Participant Characteristics	Female			
	Tertile 1 (n=999)	Tertile 2 (n=995)	Tertile 3 (n=1002)	*P* for Trend
Age, y	61±6	61±6	60±6	<0.0001
Body mass index, kg/m^2	23.63±3.82	23.80±3.83	24.71±4.20	<0.0001
Current smoker, n (%)	106 (11)	142 (14)	120 (12)	0.35
Consume alcohol, n (%)	865 (87)	853 (86)	793 (79)	<0.0001
History of cardiovascular disease, n (%)	19 (2)	12 (1)	16 (2)	0.73
Neighborhood deprivation	−2.3±0.9	−0.3±0.4	2.6±1.5	<0.0001
Education, n (%)				
No education	40 (4)	49 (5)	96 (10)	<0.0001
Secondary education	234 (23)	277 (28)	359 (36)	<0.0001
Tertiary education	725 (73)	669 (67)	547 (55)	<0.0001
Professional occupation category, n (%)*				
High	302 (31)	301 (31)	225 (23)	0.0001
Medium	483 (50)	507 (52)	612 (63)	0.043
Low	17 (2)	27 (3)	41 (4)	<0.0001
Inactive	97 (10)	71 (7)	31 (3)	<0.0001
Unemployed	60 (6)	60 (6)	69 (7)	0.42
Live alone, n (%)	325 (33)	402 (40)	435 (43)	<0.0001
Depressive symptoms, n (%)	77 (8)	81 (8)	106 (11)	0.025
Total physical activity score	6.48±1.47	6.55±1.45	6.67±1.6	0.006
Systolic blood pressure, mm Hg	128±17	128±17	129±17	0.32
Resting heart rate, bpm	62±8	62±9	63.1±9	0.001
BP lowering medication, n (%)	157 (16)	158 (16)	160 (16)	0.88
Lipid-lowering medication, n (%)	122 (13)	122 (13)	111 (12)	0.51
Glucose-lowering medication, n (%)	9 (1)	15 (2)	20 (2)	0.044
Fasting glucose, mg/dL†	4.6±0.09	4.6±0.1	4.6±0.1	0.25
Total cholesterol, mg/dL	229.1±35.2	230.2±36.8	228.1±35.2	0.55
High-density lipoprotein, mg/dL	67.9±14.7	68.5±15.6	65.5±14.7	0.0004
Triglycerides, mg/dL†	4.4±0.4	4.4±0.4	4.5±0.4	0.038

Data are mean±SD, unless otherwise indicated. BP indicates blood pressure.
*Data missing in n=183.
†Data were log transformed. Tertile 1 is least deprived, and tertile 3 is most deprived.

stiffness in all participants. Finally, in a sensitivity analysis conducted among nonindividually deprived participants (ie, from sex-specific quartile 1 of the EPICES, Table S9) ND was not related to carotid stiffness in males or females.

Discussion

The main findings of this study were: (1) markers of ID (education, living alone, occupation, and EPICES) were adversely related to carotid stiffness in males, and living alone and EPICES were adversely related to carotid stiffness in females, independently of traditional CVD risk factors; (2) ND was related to increased carotid stiffness in males only, independently of traditional risk factors; and (3) when both ID and ND were considered in the same model, significant association with carotid stiffness was observed for ID measures only. These findings imply that one's socioeconomic position, and to a lesser extent, living in a deprived neighborhood, are associated with poorer (vascular) health.

Previous research in adults examining the association between ID and arterial stiffness have focused mainly on ID markers, such as occupation, work stress[11,27,28] or shift work,[12] education, and socioeconomic status[13,14]), and have demonstrated adverse associations. In the Whitehall II study, Trudel et al[13] showed in male and female civil servants that an increase in carotid to femoral pulse wave velocity, a measure of aortic stiffness, over 5 years was higher in those with lower occupation grade, household income or education, after adjusting for traditional CVD risk factors. The current study

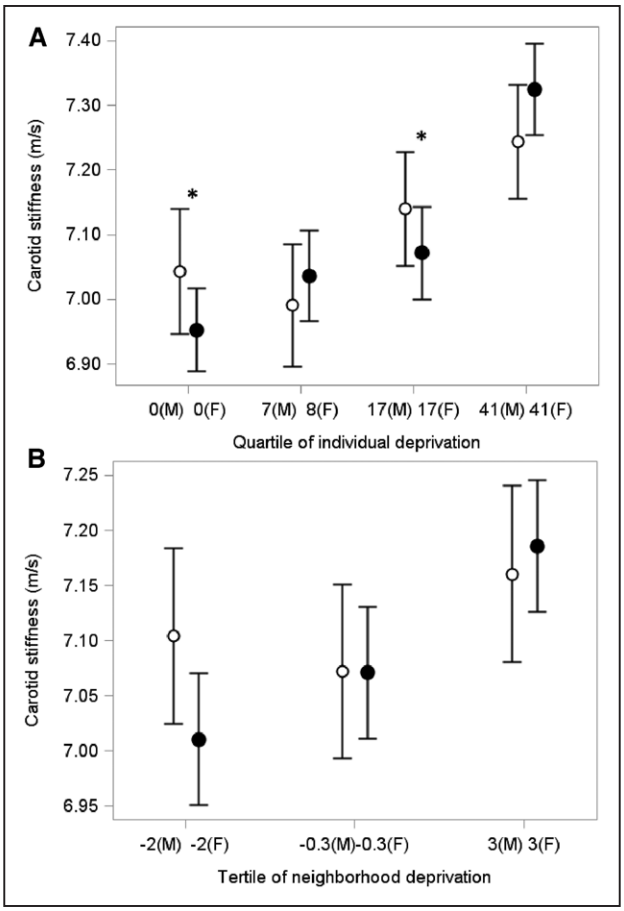

Figure. Distribution of carotid stiffness (**A**) by level of individual deprivation index (Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers EPICES score) quartiles and by neighborhood deprivation tertiles in males (black circles) and females (open circles). Data are mean and 95% CIs adjusted for age and mean blood pressure. The median EPICES for each quartile is reported in males (M) and females (F). *P* for trend; (**A**) Carotid stiffness <0.0001 in M and 0.001 in F. **B**, Carotid stiffness=0.0004 in M and 0.33 in F. *A significant difference (*P*<0.05) in carotid stiffness between M and F within the same quartile.

Table 5. Separate Association Between Individual Deprivation Markers and Carotid Stiffness in Male (n=4807) and Female (n=2996) Participants

Individual Deprivation Marker	Carotid Stiffness Regression Coefficient (95% CI)	Variance R^2
Model 1 adjusted for age, BMI, MBP, heart rate, glucose, HDL, triglycerides, alcohol, smoking, history of CVD, and physical activity		
Male		0.212
Female		0.218
Model 1+education (per decreasing level of education)		
Male	0.13 (0.07 to 0.19), *P*<0.001	0.215
Female	0.08 (–0.001 to 0.15), *P*=0.052	0.219
Model 1+living alone (yes vs. no)		
Male	0.12 (0.04 to 0.21), *P*=0.026	0.214
Female	0.10 (0.01 to 0.20), *P*=0.03	0.219
Model 1+occupation level (per decreasing level of occupation)		
Male	0.05 (0.02 to 0.08), *P*=0.0006	0.214
Female	0.01 (–0.03 to 0.06), *P*=0.51	0.218
Model 1+EPICES (per quartile)		
Male	0.08 (0.05 to 0.11), *P*<0.0001	0.217
Female	0.06 (0.02 to 0.10), *P*=0.005	0.220

Linear regression analyses were performed separately for each individual deprivation marker. Data are the multivariate-adjusted regression coefficient for the individual deprivation marker. Data were missing in n=183 for occupation level. BMI, body mass index; CVD, cardiovascular disease; EPICES, Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers; HDL, high-density lipoprotein; and MBP, mean blood pressure.

adds to these prior findings by examining the association between many distinct ID factors (education, living alone, and occupation) but also a composite marker of ID (EPICES) with carotid stiffness in a sex-specific analysis.

To our knowledge, only a few studies in adults have examined the association between ND (or proxies of) and markers of CVD.[18,29–32] However, most of these earlier studies included a smaller sample population, did not examine differences in sex, or failed to account for ID. For the first time in a large cohort, we have shown that ND is associated with increased carotid stiffness, independent of traditional CVD risk factors, in males, but not in females. In males, we observed an adverse association between ND and carotid stiffness, however, only in the highest tertile (tertile 3, most deprived).

There are many possible mechanisms that may explain the observed association between ND and elevated carotid stiffness that could not be accounted for in the current study. People living in deprived neighborhoods may be more exposed to insecurity, pollution, and noise, which in combination may elevate BP[19,33,34] and over the long term may contribute to an increase in arterial stiffness.[35] Dietary habits influence arterial stiffness,[36] but access to nutritious foods is reduced in disadvantaged areas.[37] Finally, decreased access to[38] and uptake of healthcare services[39] has been observed in disadvantaged populations and may also influence arterial stiffness.

The results on the association between ND and ID with carotid stiffness indicate sex disparities. In males, all ID measures (education, living alone, occupation and EPICES) were independently related to carotid stiffness, whereas in females only some ID measures (living alone and EPICES) were. The lack of association between education and occupation with carotid stiffness in females may be because of slightly smaller contrast in distribution of education and occupation level in females compared with males. Furthermore, ND was not related to carotid stiffness in females, contrary to men. Although speculation, an explanation for this finding may be because of differences in patterns of socialization between genders which have been suggested to favor females and result in increased social connectedness and support within their neighborhood, independent of occupational or domestic responsibilities.[40,41] However, we acknowledge that these findings need to be confirmed in future studies.

In addition, we were able to assess the respective association of ID and ND on carotid stiffness. Only ID measures remained significantly associated with carotid stiffness after mutual adjustment for ND, and ND was not significantly related to carotid stiffness in nonindividually deprived subjects. This suggests that ID measures have greater effects on carotid

Table 6. Association Between Tertiles of Neighborhood Deprivation Index and Carotid Stiffness in Male (n=4807) and Female (n=2996) Participants

Neighborhood Deprivation and Confounders	Carotid Stiffness Regression Coefficient (95% CI)			
	Male	Female	Male	Female
	Model 1		Model 2(+ EPICES)	
Tertile 1	Ref	Ref	Ref	Ref
Tertile 2	0.06 (–0.04 to 0.16), *P*=0.24	–0.03 (–0.15 to 0.08), 0.56	0.05 (–0.05 to 0.15), *P*=0.28	–0.04 (–0.15 to 0.07), *P*=0.51
Tertile 3	0.12 (0.03 to 0.22), *P*=0.012	–0.02 (–0.09 to 0.14), *P*=0.72	0.10 (0.008 to 0.19), *P*=0.052	0.01 (–0.10 to 0.13), *P*=0.85
Age	0.05 (0.04 to 0.05), *P*<0.0001	0.06 (0.05 to 0.06), *P*<0.0001	0.05 (0.04 to 0.05), *P*<0.0001	0.06 (0.05 to 0.06), *P*<0.0001
BMI	0.06 (0.05 to 0.07), *P*<0.0001	0.02 (0.003 to 0.03), *P*=0.017	0.06 (0.05 to 0.07), *P*<0.0001	0.01 (0.002 to 0.03), *P*=0.028
Mean BP	0.03 (0.03 to 0.04), *P*<0.0001	0.04 (0.04 to 0.05), *P*<0.0001	0.03 (0.03 to 0.04), *P*<0.0001	0.04 (0.04 to 0.05), *P*<0.0001
Heart rate	0.01 (0.01 to 0.02), *P*<0.0001	0.01 (0.002 to 0.01), *P*=0.008	0.01 (0.008 to 0.02), *P*<0.0001	0.007 (0.002 to 0.01), *P*=0.010
Glucose*	0.09 (–0.21 to 0.40), *P*=0.54	0.18 (–0.29 to 0.63), *P*=0.47	0.08 (–0.22 to 0.38), *P*=0.58	0.26 (–0.20 to 0.72), *P*=0.26
HDL	–0.01 (–0.01 to –0.002), *P*=0.001	–0.003 (–0.01 to 0.0009), *P*=0.14	–0.005 (–0.01 to –0.002), *P*=0.003	–0.002 (–0.006 to 0.001), *P*=0.17
Triglycerides*	0.16 (0.07 to 0.25), *P*=0.001	0.04 (–0.09 to 0.19), *P*=0.54	0.16 (0.07 to 0.26), *P*=0.0007	0.04 (–0.10 to 0.19), *P*=0.57
Alcohol	–0.12 (–0.24 to –0.004), *P*=0.042	–0.03 (–0.16 to 0.10), *P*=0.69	–0.08 (–0.19 to 0.04), *P*=0.18	–0.02 (–0.15 to 0.10), *P*=0.76
Smoking (yes/no)	–0.07 (–0.16 to 0.03), *P*=0.17	–0.11 (–0.25 to 0.03), *P*=0.13	–0.09 (–0.19 to 0.002), *P*=0.054	–0.12 (–0.26 to 0.03), *P*=0.11
History of CVD (yes/no)	–0.05 (–0.27 to 0.19), *P*=0.73	0.13 (–0.24 to 0.49), *P*=0.50	–0.06 (–0.30 to 0.17), *P*=0.59	0.11 (–0.26 to 0.48), *P*=0.55
Physical activity	–0.02 (–0.04 to 0.01), *P*=0.25	0.0004 (–0.03 to 0.03), *P*=0.98	–0.01 (–0.03 to 0.02), *P*=0.59	–0.001 (–0.04 to 0.03), *P*=0.93
EPICES	…	…	0.08 (0.05 to 0.11), *P*<0.0001	0.06 (0.02 to 0.11), *P*=0.005

Tertile 1, least deprived, is the reference group and Tertile 3 is the most deprived group.

Multilevel analysis. Data are the multivariate-adjusted regression coefficient. BMI indicates body mass index; BP, blood pressure; CVD, cardiovascular disease; EPICES, Evaluation of the Deprivation and Inequalities of Health in Healthcare Centers; and HDL, high-density lipoprotein.

*Data were log transformed.

stiffness than ND. However, we only considered socioeconomic ND, and further studies should be conducted considering exposure to noise, crime rates, perceived safety, access to fresh food, and healthcare.

The findings from the current study have potentially important implications. Given that carotid stiffness is a marker of early vascular aging and an independent risk factor for CVD,[5,6] combined preventive strategies that address both markers of ID and ND, as well as traditional risk factors, may have the greatest potential to delay arterial stiffening and reverse the growing burden of CVD worldwide. This will require a concerted effort from the individual and also health policy, education, and societal changes to influence population health. Previous work has shown that improvements in ND do bear significant health benefits (ie, reduction in systolic BP).[19] Furthermore, carotid stiffness may explain some of the association between low socioeconomic status and increased risk for CVD events and should be addressed in future work.

Our study had several strengths. We included data from a large, well-characterized study sample and used a highly specialized and sensitive technique to measure carotid stiffness parameters. The ND measure was a combination of 10 ecological level variables in the domains of social, wealth and income, education, and occupation providing a thorough description of the deprivation of each commune. However, there are also limitations that should be considered. We used carotid pulse pressure in the calculation of carotid distensibility instead of central BP. However, this approach has been recently validated in comparison with tonometry.[42] The predictive value of carotid stiffness for hard events has been established[5]; however, it does not fully represent aortic stiffness,[5,7] although both provide meaningful and partially overlapping information. Our study population was focused in Paris and surrounding suburbs, and thus, our findings may not be generalized to other populations or settings. PPS3 participants were mostly of white origin, and association between deprivation and stiffness parameters may differ by ethnicity. Other measures of ND, such as exposure to noise, crime rates, perceived safety, access to healthcare, and access to fresh food may be useful in describing the association between ND and arterial stiffness which were not available for the current analysis. The observational nature of the study limits inference regarding causality. In addition, it should be noted that the ID measures related to carotid stiffness only explained 0.1 to 0.2% of the variance. Finally, given the weak effect of deprivation on carotid stiffness, our findings should be interpreted as hypothesis generating and should be confirmed in other independent cohorts.

Conclusions

In this large study of community-dwelling healthy males and females, we have shown that individual and, to a lesser extent, ND are associated with increased carotid stiffness in males, whereas ID only is related to carotid stiffness in females. Preventive strategies that address deprivation at

both the individual and neighborhood level may be of value for avoiding early vascular aging and reducing the risk of CVD globally.

Perspectives

We have shown that individual and, to a lesser extent, ND are associated with increased carotid stiffness in males, whereas ID only is related to carotid stiffness in females. Therefore, minimizing ID and ND may be beneficial for early vascular aging.

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Disclosures

None.

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Novelty and Significance

What Is New?

- While traditional risk factors for arterial stiffness are known, the contribution of socioeconomic factors are less reported.
- In this study, we showed that socioeconomic deprivation at the individual and, to a lesser extent, neighborhood level is associated with carotid stiffness, independent of traditional risk factors in healthy males.
- Only individual deprivation is associated with carotid stiffness in healthy females.

What Is Relevant?

- Large artery stiffness is associated with high blood pressure and is an independent predictor of coronary events, stroke, and all-cause and cardiovascular mortality.
- Addressing modifiable determinants of arterial stiffness carry public health implications for the early prevention of cardiovascular disease.

Summary

Socioeconomic deprivation, both at individual and neighborhood level are associated with carotid stiffness in males. Only individual deprivation is associated with carotid stiffness in females.