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RESEARCH ARTICLE



## Neighbourhood deprivation in childhood and adulthood and risk of arterial stiffness: the Cardiovascular Risk in Young Finns study

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### ABSTRACT

**Purpose:** Individual socioeconomic status is associated with increased arterial stiffness, but limited data are available on the relations of neighbourhood deprivation with this vascular measure. We prospectively examined whether neighbourhood deprivation in childhood and adulthood predicts arterial stiffness indicated by pulse wave velocity (PWV).

**Materials and methods:** The study population comprised 1,761 participants aged 3-18 years at baseline (1980) from the longitudinal Cardiovascular Risk in Young Finns cohort study. PWV was measured in 2007 by whole-body impedance cardiography at ages 30-45 years. Cumulative lifetime neighbourhood deprivation was assessed using data from socioeconomic circumstances in participants' lifetime residential neighbourhoods, categorised as low versus high deprivation.

**Results:** High deprivation in childhood and adulthood was associated with higher PWV in adulthood after adjustment for age, sex, and place of birth (mean difference = 0.57 m/s, 95%CI = 0.26-0.88, P for trend = 0.0004). This association was attenuated but remained statistically significant after further adjustment for childhood parental socioeconomic status and adulthood individual socioeconomic status (mean difference = 0.37 m/s, 95%CI = 0.05-0.70, P for trend 0.048). Also, low individual socioeconomic status in adulthood was associated with higher PWV when adjusted for age, sex, place of birth, parental socioeconomic status in childhood, and lifetime neighbourhood deprivation (mean difference = 0.54 m/s, 95%CI = 0.23-0.84, P for trend 0.0001).

**Conclusion:** These findings suggest that lifetime neighbourhood deprivation and low adulthood socioeconomic status are independent risk factors for increased arterial stiffness in adulthood.

### PLAIN LANGUAGE SUMMARY

- Limited data is available about the association between neighbourhood deprivation and arterial stiffening.
- We prospectively examined whether neighbourhood deprivation in childhood and adulthood predicts arterial stiffness indicated by pulse wave velocity (PWV) in 1,761 participants aged 3-18 years at baseline (1980) from the longitudinal Cardiovascular Risk in Young Finns cohort study.
- PWV was measured by whole-body impedance cardiography at ages 30-45 years. Cumulative lifetime neighbourhood deprivation was assessed using data from socioeconomic circumstances in participants' lifetime residential neighbourhoods, categorised as low versus high deprivation.

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- high lifetime neighbourhood deprivation was associated with high PWV in adulthood independently of childhood parental SES and adulthood individual SES.
- Low individual SES in adulthood was also associated with higher PWV in adulthood and this association was robust to adjustment for parental SES in childhood and lifetime neighbourhood deprivation.
- These findings suggest that neighbourhood deprivation and low adulthood socioeconomic status are independent risk factors for increased arterial stiffness in adulthood.

## Introduction

Socioeconomic circumstances influence lifestyle, conditions at work and at home, and the environment, therefore being powerful predictors of health. Numerous studies have linked low socioeconomic status (SES), indicated by low educational attainment, income, and occupational status, to increased morbidity and mortality (Adler and Ostrove 1999), including non-fatal and fatal cardiovascular disease (Kaplan and Keil 1993). In addition, socioeconomic characteristics of the residential areas may affect health (Pickett and Pearl 2001; Diez Roux and Mair 2010). Studies have found excess cardiovascular disease rates in residents of deprived neighbourhoods characterised by high unemployment rate and low educational level (Diez Roux and Mair 2010; Brown et al. 2011; Mohammed et al. 2019; Kivimäki et al. 2020). Neighbourhood deprivation, regardless of individual SES, has been associated with an increased risk of hypertension, diabetes, stroke, coronary heart disease, and myocardial infarction (Diez Roux et al. 2001; Carlsson et al. 2016; Claudel et al. 2018; Kivimäki et al. 2021).

Fewer studies have examined the effects of SES and neighbourhood socioeconomic circumstances on preclinical changes in the vascular system. High arterial stiffness, describing the rigidity of arterial walls is a typical consequence of atherosclerosis, increasing the risk of cardiovascular and all-cause mortality (Vlachopoulos et al. 2010). Pulse wave velocity (PWV) is a non-invasive measure of arterial stiffness. Unfavourable SES in childhood and adulthood correlate with higher PWV in adulthood, suggesting that adults with lower SES tend to have stiffer arteries (Trudel et al. 2016; Coelho et al. 2019; Kim et al. 2020; Puolakka et al. 2017). However, little is known about the association between neighbourhood deprivation and arterial stiffening.

In the current study, we examined if neighbourhood deprivation across the life course is associated with adulthood arterial stiffness independently of individual adulthood SES and childhood parental SES.

## Material and methods

### Study design and population

This study is part of the longitudinal cohort study The Cardiovascular Risk in Young Finns conducted in five Finnish cities with medical schools and their rural surroundings. The main target of the study was to detect cardiovascular risk factors from childhood to adulthood around Finland. A detailed description of the study design has been published earlier (Raitakari et al. 2008). After the first cross-sectional study in 1980 several follow-up studies have been carried out. The baseline study population comprised of 3596 participants aged 3–18 years. In 2007, a follow-up with 2204 participants was performed. After excluding participants with missing data, the analytic sample of the current study includes those 1761 participants who underwent PWV measurements and whose lifetime neighbourhood characteristics were available. The study was approved by local ethics committees (ETL-R07100). All participants gave their written informed consent, and the studies were conducted in accordance with the Declaration of Helsinki.

### Childhood and adulthood cardiovascular risk factors

Standard methods were used to determine childhood and adulthood blood pressure, high-density lipoprotein (HDL) cholesterol, LDL cholesterol, triglycerides and glucose (in 2007) as previously described in detail (Raiko et al. 2010; Juonala et al. 2011; Oikonen et al. 2016). Smoking status was dichotomised (1 = daily smoking, 0 = not daily smoking). Body mass index (BMI, kg/m<sup>2</sup>) was calculated by dividing the weight in kilograms by the square of the height in metres.

### Neighbourhood deprivation

Participants were linked to data on neighbourhood deprivation derived from Statistics Finland using residential addresses. A comprehensive report of this data formation has been described earlier (Kivimäki

et al. 2018). In brief, all Finnish residential areas have been divided into 250 m<sup>2</sup> grids (with  $\geq 10$  residents) and grids have been categorised with Z-score scale reflecting neighbourhood deprivation in relation to the national mean. Z-score (mean 0, SD 1) has been formed according to the proportion of adult residents with primary education only, the unemployment rate, and the proportion of people living in rented housing. These variables were standardised to obtain a Z-score for each neighbourhood feature. The mean of these values is the neighbourhood deprivation Z-score (mean = 0, SD = 1). The higher the score the higher the neighbourhood deprivation is. Using three cut-offs (-0.5, 0, and 0.5), we categorised neighbourhood deprivation Z-score into four groups: low (Z-score  $\leq -0.5$ ), low intermediate ( $> -0.5$ –0), high intermediate ( $> 0$ –0.5) and high ( $> 0.5$ ) neighbourhood deprivation. Lifetime cumulative neighbourhood deprivation Z-score was the mean of the residential time-weighted neighbourhood deprivation Z-scores during the entire follow-up. Information about participants' residential history with dates of moves was obtained from the Finnish Population Register Centre.

### **Parental and adulthood individual SES**

Parental SES, a measure of SES in childhood, was defined using three indicators: educational attainment, mean household income, and unemployment (yes or no) of the parent or parents during the participants' childhood. Adulthood individual SES was obtained from information on participants' educational attainment, mean income, and unemployment in adulthood. Standardised scores (mean 0, SD 1) of aforementioned education and income variables and also unemployment score (-1 for the history of unemployment and 0 for no unemployment) were summed up and the mean of these scores for both parental and individual adulthood SES were divided into quartiles. Higher scores represent higher SES.

### **Pulse wave velocity measurement**

Measurements of arterial PWV were performed in 2007 with a whole-body impedance cardiography device (CircMonR, JR Medical Ltd, Tallinn, Estonia). The method includes whole-body impedance cardiography, distal impedance plethysmography, and an ECG channel. Standard electrodes were placed on the body surface: for the whole-body impedance measurement a pair of current electrodes on the wrist and ankles, and a pair of voltage electrodes 5 cm

proximal to the aforementioned current electrodes, and for the distal impedance plethysmography measurement the active electrode on the lateral side of the knee joint and reference electrode about 20 cm distal to it on the calf. The method registers continuous changes in body electrical impedance during a cardiac cycle. The whole-body impedance decreases when the pulse pressure wave enters the aortic arch and popliteal artery impedance decreases when the pulse pressure wave later enters the lower limb. The aortic-popliteal PWV can be calculated by the CircMonR device software from the pulse transit time and the approximate distance between the aortic arch and the popliteal artery. The measurement method and its validation procedure have been introduced in detail earlier (Aatola et al. 2010; K  obi et al. 2003). This method has been detected to have good repeatability and reproducibility values and measurements have excellent correlation ( $r=0.82$ ) with tonometric PWV method measurements (Tahvanainen et al. 2009; Wilenius et al. 2016).

### **Statistical analysis**

The description of variables was done by calculating frequencies and proportions (categorical variables) or means and standard deviations (continuous variables) for low, low intermediate, high intermediate, and high cumulative neighbourhood deprivation groups. A random-coefficient generalised mixed model was used for the analysis of mean differences (and 95% confidence intervals) of PWV between parental and individual SES groups and between cumulative neighbourhood deprivation groups. For parental and adulthood individual SES, the highest quartile ( $> 0.5$  SD) was the reference. For neighbourhood deprivation reference was the lowest group ( $< -0.5$  SD). Analyses were adjusted for age, sex, place of birth (Eastern or Western Finland) (model 1), and also for childhood parental and adulthood individual SES (model 2). Finally, analyses were further adjusted for adulthood BMI, systolic blood pressure, LDL cholesterol, HDL cholesterol, triglycerides, glucose and daily smoking (model 3). P-value  $< 0.05$  was considered statistically significant. SAS version 9.4 was used for the statistical analyses (SAS Institute, Cary, NC, USA).

### **Results**

The baseline characteristics of the study participants are presented in Table 1. At baseline, the mean age of participants was 11.2 years, and 55.1% were women.

High lifetime neighbourhood deprivation was associated with higher PWV in adulthood after adjustment for age, sex, and place of birth (mean difference = 0.57 m/s, 95%CI = 0.26-0.88, *P* for trend = 0.0004). This association was partially diluted but remained significant after further adjustment with childhood parental SES and adulthood individual SES (mean difference = 0.37 m/s, 95%CI = 0.05-0.70, *P* for trend 0.048) (Table 2). After further adjustment for adulthood BMI, systolic blood pressure, LDL cholesterol, HDL cholesterol and triglycerides this association diluted to nonsignificant (*P* for trend 0.07).

**Table 1.** Characteristics of the participants at baseline in 1980 and in follow-up in 2007.

Number of participants	1761
Age in 1980, years, mean (SD)	11.2 (4.5)
Sex	
Women, N (%)	971 (55.1)
Men, N (%)	790 (44.9)
Place of birth	
Eastern Finland, N (%)	845 (48.0)
Western Finland, N (%)	916 (52.0)
Cardiovascular risk factors in 1980	
BMI, mean (SD)	17.9 (3.2)
Systolic blood pressure, mean (SD)	113 (11)
LDL cholesterol, mean (SD)	3.4 (0.8)
HDL cholesterol, mean (SD)	1.6 (0.3)
Triglycerides, mean (SD)	0.7 (0.3)
Daily smoking (%)	11.9%
Cardiovascular risk factors in 2007	
BMI, mean (SD)	26.0 (4.8)
Systolic blood pressure, mean (SD)	120 (14)
LDL cholesterol, mean (SD)	3.1 (0.8)
HDL cholesterol, mean (SD)	1.3 (0.3)
Triglycerides, mean (SD)	1.4 (0.9)
Glucose, mean (SD)	5.3 (0.8)
Daily smoking, (%)	19.4%

Low parental SES in childhood was associated with higher PWV in adulthood when adjusted for age, sex, and place of birth (mean difference = 0.45 m/s, 95%CI = 0.18-0.72, *P* for trend 0.004). This association disappeared after further adjustment for adulthood individual SES and lifetime neighbourhood deprivation (mean difference = 0.22 m/s, 95%CI = -0.07-0.51, *P* for trend 0.48) (Table 2).

Low individual SES in adulthood was associated with higher PWV in adulthood when adjusted for age, sex, and place of birth (mean difference = 0.68 m/s, 95%CI = 0.40-0.97, *P* for trend < 0.0001). This association remained significant after further adjustment for parental SES in childhood and lifetime neighbourhood deprivation (mean difference = 0.54 m/s, 95%CI = 0.23-0.84, *P* for trend 0.0001) (Table 2). After further adjustment for adulthood BMI, systolic blood pressure, LDL cholesterol, HDL cholesterol and triglycerides this association remained significant (*P* for trend 0.002).

## Discussion

This study showed that high lifetime neighbourhood deprivation was associated with high PWV in adulthood independently of childhood parental SES and adulthood individual SES. Low individual SES in adulthood was also associated with higher PWV in adulthood and this association was robust to adjustment for parental SES in childhood and lifetime neighbourhood deprivation.

A previous study using the same cohort found that high neighbourhood deprivation was associated

**Table 2.** SES and pulse wave velocity.

Socioeconomic indicator	<i>n</i> = 1759-1761, (%)	Mean difference (95 % CI)	
		Separately*	In the same model†
Parental SES			
>0.5 SD (high)	313 (17.8)	0.00 (reference)	0.00 (reference)
≥0 to 0.5 SD	499 (28.4)	0.33 (0.08-0.58)	0.22 (-0.03-0.47)
-0.5 to < 0 SD	580 (33.0)	0.30 (0.06-0.55)	0.14 (-0.11-0.40)
<-0.5 SD (low)	368 (20.9)	0.45 (0.18-0.72)	0.22 (-0.07-0.51)
Test for trend		<i>P</i> <sub>trend</sub> = 0.004	<i>P</i> <sub>trend</sub> = 0.418
Adulthood individual SES			
>0.5 SD (high)	304 (17.3)	0.00 (reference)	0.00 (reference)
≥0 to 0.5 SD	489 (27.8)	0.25 (-0.00-0.50)	0.19 (-0.07-0.45)
-0.5 to < 0 SD	672 (38.2)	0.44 (0.20-0.68)	0.34 (0.08-0.59)
<-0.5 SD (low)	294 (16.7)	0.68 (0.40-0.97)	0.54 (0.23-0.84)
Test for trend		<i>P</i> <sub>trend</sub> < 0.0001	<i>P</i> <sub>trend</sub> = 0.0001
Neighbourhood deprivation‡			
<-0.5 SD (low)	318 (18.1)	0.00 (reference)	0.00 (reference)
<0.0 to -0.5 SD	750 (42.6)	0.42 (0.19-0.65)	0.36 (0.13-0.59)
0.0 to 0.5 SD	489 (27.8)	0.45 (0.20-0.69)	0.31 (0.06-0.57)
>0.5 SD (high)	204 (11.6)	0.57 (0.26-0.88)	0.37 (0.05-0.70)
Test for trend		<i>P</i> <sub>trend</sub> = 0.0004	<i>P</i> <sub>trend</sub> = 0.048

\*Adjusted for age, sex and place of birth (Eastern or Western Finland).

†Adjusted for age, sex, place of birth (Eastern or Western Finland) and adulthood individual SES + neighbourhood deprivation (parental SES), or parental SES + neighbourhood deprivation (adulthood individual SES) or parental + adulthood individual SES (neighbourhood deprivation).

‡Lifetime cumulative neighbourhood deprivation.



with undesirable cardiometabolic risk factors and increased incidence of diabetes (Kivimäki et al. 2018). Several other studies have shown that favourable childhood family SES or individual SES correlates with lower PWV in adulthood (Trudel et al. 2016; Coelho et al. 2019; Kim et al. 2020). We have also reported previously an association between higher childhood family SES (assessed as family income) and lower arterial stiffness in adulthood even when adjusting for the participant's own SES in adulthood (Puolakka et al. 2017). The current study extends these findings by showing that lifetime neighbourhood deprivation and low individual SES in adulthood were associated with higher adulthood PWV independently with each other and childhood parental SES. Previous findings from analyses that emulated nonrandomised neighbourhood modification trials suggest that favourable modifications to residential neighbourhoods might contribute to healthy lifestyle choices and could lead to potentially important reductions in a range of specific morbidities over time (Kivimäki et al. 2021). Potential mechanisms underlying the association of neighbourhood deprivation and arterial stiffness may include characteristics of disadvantaged neighbourhoods that modify risk profiles and disease occurrences, such as being exposed to major roads and air pollution (Chen et al. 2013; Chen et al. 2017), low availability of healthy food outlets, and residential walkability (Creatore et al. 2016; Tabaei et al. 2018), neighbourhood violence (Theall et al. 2017) and lack of support for smoking cessation (Pulakka et al. 2016; Diez Roux et al. 2003; Halonen et al. 2016).

Recent study using the same cohort showed that high neighbourhood deprivation was associated with several undesirable cardiometabolic risk factors, such as increased prevalence of daily smoking, higher BMI, elevated systolic blood pressure and elevated triglycerides (Kivimäki et al. 2018). As expected, after adjustment for cardiovascular risk factors in adulthood the association with neighbourhood deprivation and PWV diluted, suggesting that the association was at least partially mediated through unfavourable influence of neighbourhood deprivation on cardiovascular risk factors.

Strengths of our study include its large cohort of young children and adolescents and a follow-up over 27 years from childhood to adulthood. However, our study cohort was ethnically rather homogenous, consisting solely of white European participants. Therefore, the results may not be generalisable to other ethnicities. In addition, observational studies cannot establish causality, and the impact of both

baseline values and the changes in risk factors during follow-up could have been under or overestimated due to possible regression dilution bias.

In conclusion, the present study has demonstrated that high lifetime neighbourhood deprivation might accelerate arterial stiffening in adulthood independently of childhood socioeconomic circumstances and adulthood individual SES. We also confirmed that low individual SES in adulthood was associated with higher arterial stiffness in adulthood even after adjustment for parental SES in childhood and lifetime neighbourhood deprivation.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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