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Influence of early life risk factors and lifestyle on systemic vascular resistance in later adulthood: the cardiovascular risk in young Finns study

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ABSTRACT

Purpose: There are limited data available concerning the effects of lifetime risk factors and lifestyle on systemic hemodynamics, especially on systemic vascular resistance. The purpose of the study was to evaluate how lifetime cardiovascular risk factors (body mass index (BMI), high-density lipoprotein, low-density lipoprotein, triglycerides, systolic blood pressure, blood glucose) and lifestyle factors (vegetable consumption, fruit consumption, smoking and physical activity) predict systemic vascular resistance index (SVRI) and cardiac index (CI) assessed in adulthood.

Materials and Methods: Our study cohort comprised 1635 subjects of the Cardiovascular Risk in Young Finns Study followed up for 27 years since baseline (1980; aged 3–18 years, females 54.3%) who had risk factor and lifestyle data available since childhood. Systemic hemodynamics were measured in 2007 (aged 30–45 years) by whole-body impedance cardiography.

Results: In the multivariable regression analysis, independent predictors of the adulthood SVRI were childhood BMI, blood glucose, vegetable consumption, smoking, and physical activity ($p \leq .046$ for all). Vegetable consumption, smoking, and physical activity remained significant when adjusted for corresponding adult data ($p \leq .036$ for all). For the CI, independent predictors in childhood were BMI, systolic blood pressure, vegetable consumption, and physical activity ($p \leq .044$ for all), and the findings remained significant after adjusting for corresponding adult data ($p \leq .046$ for all). The number of childhood and adulthood risk factors and unfavourable lifestyle factors was directly associated with the SVRI ($p < .001$) in adulthood. A reduction in the number of risk factors and unfavourable lifestyle factors or a favourable change in BMI status from childhood to adulthood was associated with a lower SVRI in adulthood ($p < .001$).

Conclusion: Childhood BMI, blood glucose, vegetable consumption, smoking and physical activity independently predict systemic vascular resistance in adulthood. A favourable change in the number of risk factors or BMI from childhood to adulthood was associated with lower vascular resistance in adulthood.

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Hemodynamics; systemic vascular resistance; risk factors; lifestyle

Introduction

Hypertension is an important public health challenge globally, with 1.56 billion adults predicted to have hypertension in 2025 worldwide [1]. It has been estimated to cause 13% of deaths globally [2]. The prevention of hypertension is one of the most important ways to reduce deaths and disability from cardiovascular diseases [3]. Early identification of individuals at risk of elevated blood pressure has important implications for prevention, e.g. lifestyle modifications.

Blood pressure is mainly determined by cardiac output and systemic vascular resistance. Typically,

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Supplemental data for this article can be accessed here.

high systemic vascular resistance causes hypertension [4–7]. We have recently shown that systemic vascular resistance predicts the incidence of hypertension even in normotensive young adults [8]. Even though elevated vascular resistance appears to have an important role in the development of hypertension, there are limited data available concerning lifetime (from childhood to adulthood) risk factors and lifestyle as determinants of adulthood systemic vascular resistance. Impaired glucose tolerance [9], type 2 diabetes [9], metabolic syndrome [10], an increasing number of metabolic syndrome components [10], hypertension [11], and abdominal obesity [12] have been shown to be associated with increased systemic vascular resistance in cross-sectional experiments in adults. Concerning other risk factors and lifestyle, low-density lipoprotein (LDL) cholesterol [13] and smoking [14] have also been reported to be cross-sectionally associated with systemic vascular resistance in adults.

To the best of our knowledge, no information has been published concerning the effect of lifetime cardiovascular risk factors and lifestyle factors on systemic hemodynamics, especially on vascular resistance. Therefore, the aim of the present study was to analyse the combined effects of child and adult cardiovascular risk factors and lifestyle factors on systemic vascular resistance and cardiac output in the prospective Cardiovascular Risk in Young Finns Study.

Methods

Study population

The Cardiovascular Risk in Young Finns Study is a large, ongoing, multicenter, longitudinal, population-based study of cardiovascular risk factors in Finland. The first cross-sectional study was conducted in 1980 with 3596 participants aged 3–18 years. Several follow-up studies with extensive cardiovascular risk factor and lifestyle factor recordings have been performed since then. In 2007, 1872 men and women underwent systemic hemodynamic measurements. After excluding subjects with incomplete risk factors, lifestyle factors or hemodynamic data, pregnant women, and subjects with type 1 or type 2 diabetes, hypertension, an antihypertensive or cholesterol-lowering medication, a total of 1635 men and women were included in the present analysis. The study design and protocol have been described in detail previously [15]. The study was approved by local ethics committees, and informed consent was obtained from all participants.

Clinical measurements and questionnaires

Standard methods were used to determine blood pressure, high-density lipoprotein (HDL) cholesterol, LDL cholesterol, triglycerides, and fasting serum glucose [16–18].

Questionnaires using self-reports were completed to collect data on dietary habits, smoking, and physical activity as previously described in detail [19]. Smoking was assessed in subjects aged $\geq$12 years. Smoking was defined as regular cigarette smoking on a daily basis in adolescence and in adulthood. Information on dietary habits was obtained with a nonquantitative food frequency questionnaire (FFQ). For subjects aged 3–9 years, the data were requested from the parents, and at the ages of 12–18 years, study subjects were assisted by their parents when necessary. To examine the frequency of fruit and vegetable consumption, the subjects were asked to fill in a questionnaire on habitual dietary choices for the past month with six response categories: 1 = daily, 2 = almost every day, 3 = a couple of times per week, 4 = about once a week, 5 = a couple of times per month, and 6 = more seldom. The response categories were converted into times of consumption per month (1→35; 2→25; 3→10; 4→4; 5→2; 6→0). In 2007, a more detailed quantitative FFQ providing an estimate of food consumption in grams/day was introduced [20,21].

Physical activity was assessed by a self-report questionnaire [22] from the age of 9 years with the parents' assistance if necessary. The questions concerned the frequency and intensity of leisure-time physical activity, participation in sports club training, participation in sports competitions, and habitual ways of spending leisure time. In adulthood, the physical activity questionnaire consisted of the following variables: intensity of physical activity, frequency of vigorous physical activity, hours spent on vigorous physical activity, the average duration of a physical activity session, and participation in organised physical activity. A physical activity index (range 5–15) was calculated by summing these variables. The lowest scores indicate more sedentariness, and the highest scores indicate a more active condition [22].

Systemic hemodynamics

Participants were instructed to avoid heavy exercise and alcohol on the previous evening and smoking, caffeine-containing products, and heavy meals on the investigation day. A trained research nurse carried out the measurements in a quiet and temperature-

controlled room. Participants laid in the supine position for at least 15 min before the measurement, during which period electrodes for whole-body impedance cardiography were placed on the body surface. A whole-body impedance cardiography (ICG_{WB}) device (CircMon B202, JR Medical Ltd, Tallinn, Estonia) was used to determine the beat-to-beat cardiac index (CI; cardiac output/body surface area, l/min/m^2) and systemic vascular resistance index (SVRI; systemic vascular resistance/body surface area, dyn*s/cm^5*m^2). Briefly, CircMon records the continuous changes in body electrical impedance during a cardiac cycle. The stroke volume and cardiac output values measured with CircMon are in agreement with the values measured by the thermodilution method and 3-dimensional echocardiography [23–25]. The repeatability of cardiac output measurements by the impedance method has been reported to be even better than that by the thermodilution method [23]. A more detailed description of the method has been previously reported [23,24].

Statistics

To study the effects of risk variables and lifestyle risk factors on hemodynamics (SVRI and CI), we calculated age- and sex-specific Z scores for each risk variable in each study year. Childhood risk variable load was assessed by calculating the average Z scores from 1980, 1983, and 1986. In these analyses, only measurements conducted at ages 3–18 years were used. Adulthood risk variable load was assessed by calculating the average Z scores in 2001 and 2007.

To examine whether sex modifies the associations between risk variables and hemodynamics, we included sex × risk variable interaction terms in the regression models. These analyses were performed separately for each risk variable. The associations between risk variables and hemodynamics were of similar magnitude in both sexes. Therefore, the results are shown with the sexes combined. The univariate relations between study variables and hemodynamics were examined using regression analysis. To study the independent effects of risk variables on hemodynamics, stepwise multivariable models were constructed. To study whether the effects of childhood risk factors are independent of current risk factors, we fitted a multivariable model including adulthood data on those risk factors with significant effects in the childhood multivariable model.

To examine the effect of multiple risk factors and lifestyle factors on hemodynamics, we calculated a risk score, determined by the number of risk factors and lifestyle factors. Risk factors and lifestyle factors were defined as values at or above the age- and sex-specific 80th percentile for LDL cholesterol, systolic blood pressure, and body-mass index (BMI, kg/m^2); at or below the 20th percentile for HDL cholesterol, fruit consumption, and physical activity; and smoking (assessed in subjects ≥12 years of age). The mean number of risk factors and unfavourable lifestyle factors was 1.36 (range, 0–6) in childhood and 1.44 (range, 0–6) in adulthood. Because smoking was only evaluated in children aged 12 years or older, we repeated all analyses using the number of risk factors and lifestyle factors that did not include smoking as a risk variable and obtained essentially similar results. Linear regression analysis was used to test the associations between the number of risk factors and lifestyle factors and the linear trend in the SVRI.

In addition, we studied whether changes in the risk factor and lifestyle factor score and obesity status between childhood and adulthood were associated with the SVRI. In these analyses, the presence of ≥1 risk factor or unfavourable lifestyle factor was considered an unfavourable status, and a cut-off point of the age- and sex-specific 50th percentile for BMI was used to determine favourable or unfavourable obesity status. We used *t* tests to assess whether subjects with unfavourable status in childhood and favourable status in adulthood, favourable status in childhood and unfavourable status in adulthood, and favourable status both in childhood and adulthood differed from those having an unfavourable status in childhood and in adulthood.

Values for triglycerides and blood glucose were log10-transformed before analyses because of skewed distributions. All analyses were performed with SPSS for Windows (release 26.0.0.0, SPSS Inc.). Statistical significance was inferred at a two-tailed *P*-value $< .05$.

Results

The baseline characteristics of the study participants are presented in Table 1. The characteristics of participants ($n = 1635$) and nonparticipants ($n = 1961$) of the present study were compared. Among the nonparticipants, there were more males than females ($p < .001$), and they had significantly higher BMI and systolic blood pressure ($p = .029$ and $p = .001$, respectively). No statistically significant differences were seen in other risk factors (Table 1).

In univariate analysis, BMI, systolic blood pressure, blood glucose, vegetable consumption, smoking, and

Table 1. Baseline characteristics in 1980 of the study participants and nonparticipants (subjects lost or excluded).

Variable	Participants	Nonparticipants	*P*-value
No. of subjects	1635	1961	
Sex, (% female)	54.3	48.2	<.001
Age, y	10.6 ± 5.0	10.3 ± 5.0	.142
BMI, kg/m^2	17.8 ± 2.9	17.9 ± 3.2	.029
Systolic blood pressure, mmHg	112 ± 12	113 ± 13	.001
HDL cholesterol, mmol/L	1.56 ± 0.30	1.56 ± 0.31	.883
LDL cholesterol, mmol/L	3.41 ± 0.79	3.45 ± 0.87	.128
Triglycerides, mmol/L	0.60 (0.45–0.78)	0.60 (0.45–0.79)	.425
Glucose, mmol/L*	4.64 ± 0.45	4.73 ± 1.07	.101
Vegetables, consumption frequency per month	24 ± 11	24 ± 11	.171
Fruits, consumption frequency per month	26 ± 10	26 ± 10	.593
Smoking (% of subjects)†	11.1	13.6	.131
Physical activity index†	9.0 ± 1.8	9.1 ± 1.8	.872

Values are presented as the mean ± standard deviation, geometric mean (25th–75th percentile) or percentage of subjects. BMI indicates body mass index; HDL, high-density lipoprotein; LDL, low-density lipoprotein. Comparisons between participants and nonparticipants were performed with the use of age- and sex-adjusted regression analysis for continuous variables and χ^2 tests for categorical variables.
*Glucose levels are from the study year 1986.
†Smoking data were gathered from subjects aged 12–18 years and physical activity among those aged 9–18 years old.

Table 2. Relations between childhood (ages 3–18 years, between 1980 and 1986) risk factor and lifestyle factor load and the SVRI in adulthood.

Risk variable	β ± SE	*P*-value
(A) Univariate models–childhood		
Body mass index	59.8 ± 14.0	<.001
Systolic blood pressure	47.7 ± 15.6	.002
HDL cholesterol	−24.7 ± 14.4	.087
LDL cholesterol	3.0 ± 14.3	.835
Triglycerides	17.5 ± 15.6	.261
Glucose*	34.2 ± 15.0	.023
Vegetable consumption	−44.5 ± 15.6	.004
Fruit consumption	1.5 ± 15.5	.924
Smoking†	89.5 ± 35.2	.011
Physical activity†	46.5 ± 14.5	.001
(B) Multivariable model–childhood		
Body mass index	51.0 ± 15.9	.001
Glucose	29.9 ± 15.0	.046
Vegetable consumption	−54.4 ± 19.1	.004
Smoking	90.1 ± 40.7	.027
Physical activity	53.0 ± 16.6	.001
(C) Multivariable model–childhood-adulthood		
Childhood body mass index	−25.9 ± 19.6	.186
Adulthood body mass index	131.9 ± 19.3	<.001
Childhood glucose	27.2 ± 15.5	.080
Adulthood glucose	−8.0 ± 18.6	.665
Childhood vegetable consumption	−48.5 ± 19.3	.012
Adulthood vegetable consumption	−31.9 ± 18.3	.081
Childhood smoking	146.5 ± 42.3	.001
Adulthood smoking	−116.1 ± 37.5	.002
Childhood physical activity	35.5 ± 16.9	.036
Adulthood physical activity	63.1 ± 17.7	<.001

(A) Univariate associations between childhood risk factors and lifestyle factors and the SVRI. (B) Multivariable model for associations between childhood risk factors and lifestyle factors and the SVRI. (C) Multivariable model including those risk factors and lifestyle factors with independent effects on the SVRI in the childhood multivariable model and taking into account the effects of respective adulthood risk factors and lifestyle factors. Beta-values are regression coefficients (expressed in dyn*s/cm5*m2) for a 1-SD change in continuous variables. *P*-values are from linear regression models.
*Glucose levels are from the study year 1986.
†Smoking data were gathered on subjects aged 12–18 years old and physical activity among those aged 9–18 years old.

physical activity index ($p \leq .023$ for all) in childhood were significantly associated with the SVRI in adulthood (Table 2, A). In multivariable regression analysis, childhood BMI, blood glucose level, smoking, and physical activity were directly associated with the SVRI, and vegetable consumption was inversely associated with adulthood SVRI (Table 2, Model B). When taking into account the effects of adulthood risk variables, the associations between vegetable consumption, smoking, and physical activity with adulthood SVRI remained significant (Table 2, Model C).

A composite childhood risk factor and unfavourable lifestyle factor score was associated with the SVRI (Figure 1, A), and this effect remained significant when adjusted for the adulthood score (Figure 1, B). An increasing trend in adulthood SVRI was also observed across the groups with an increasing number of adulthood risk factors and unfavourable lifestyle factors ($p < .001$; Supplemental figure). Participants with one or more risk factors or unfavourable lifestyle factors both in childhood and adulthood had higher SVRIs in adulthood than those with one or more risk factors or unfavourable lifestyle factors in childhood but no risk factors or unfavourable lifestyle factors in adulthood ($p < .001$; Figure 2 A). Similarly, a favourable change in BMI between childhood and adulthood was associated with a lower SVRI in adulthood, and an unfavourable change was associated with a higher SVRI ($p < .001$ and $p = .045$, respectively; Figure 2 B).

Childhood BMI and physical activity were indirectly associated, and systolic blood pressure and vegetable consumption were directly associated with adulthood CI and remained significant in the multivariable model with adulthood risk factor and lifestyle factor data (Supplemental table, models B and C). However, the number of childhood and adulthood risk factors and unfavourable lifestyle factors was not significantly associated with the CI in adulthood

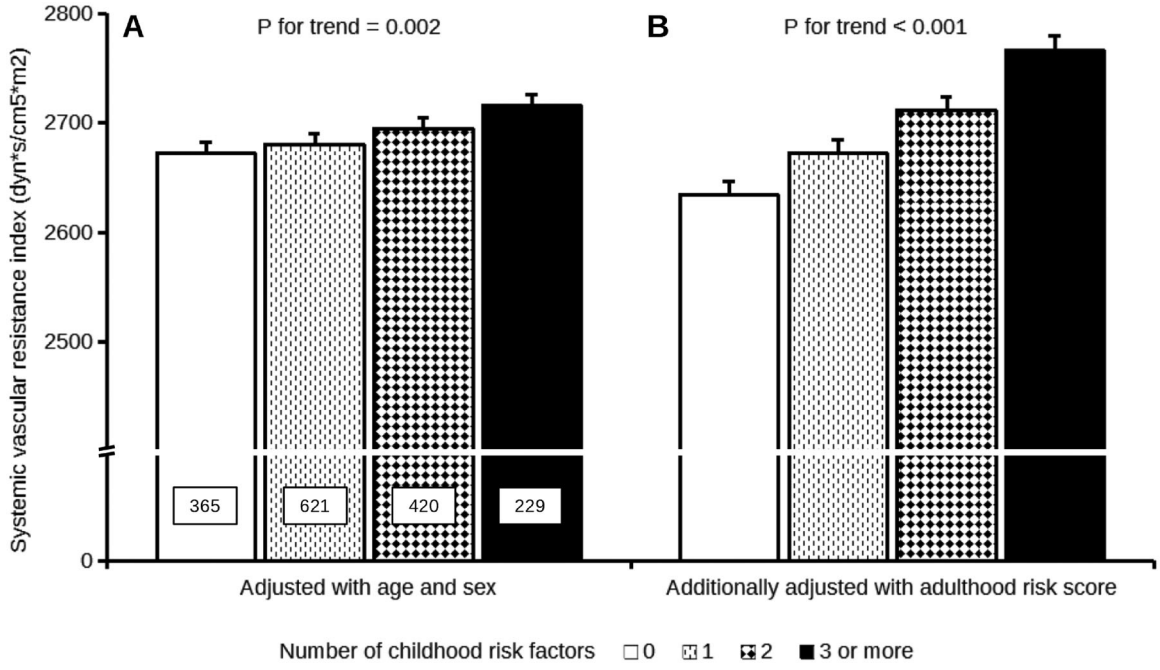

Figure 1. Associations between the number of childhood risk factors and unfovarable lifestyle factors (load variable 1980–1986), including LDL cholesterol, HDL cholesterol, systolic blood pressure, BMI, fruit consumption, physical activity (extreme quintile was considered a risk factor), and smoking with the SVRI in adulthood. The results in (A) were adjusted for age and sex, and the results in (B) were additionally adjusted with similar adulthood risk scores (load variables 2001–2007). Bars represent the mean plus 95% confidence interval. Values inside columns indicate the number of subjects in each group. The *P*-values for trends are from linear regression analyses.

($p = .688$ and $p = .647$, respectively), and a reduction in the number of risk factors and unfavourable lifestyle factors from childhood to adulthood was not significantly associated with the CI in adulthood ($p = .411$, data not shown).

Discussion

The current study showed that in the multivariable regression analysis of childhood risk factors and lifestyle factors, independent predictors of adulthood SVRI were childhood BMI, blood glucose, vegetable consumption, smoking, and physical activity. Of these, vegetable consumption, smoking, and physical activity remained significant when adjusted for corresponding adult data. Independent childhood predictors of adulthood CI were BMI, systolic blood pressure, vegetable consumption, and physical activity, all of which remained significant after adjustment for corresponding adulthood data. We also observed that the number of childhood and adulthood risk factors and lifestyle factors directly correlated with adult SVRI. In addition, favourable changes in the number of risk factors and unfavourable lifestyle factors or favourable changes in BMI were associated with a lower SVRI in adulthood.

Previous studies concerning the relationship between lifetime risk factors and lifestyle factors and the SVRI are limited. Koivistoinen *et al.* showed that glucose tolerance, as well as 2-h blood glucose and 2-h blood insulin from oral glucose tolerance tests, were associated with the SVRI in adults [9]. In a previous cross-sectional analysis of the current cohort, metabolic syndrome and an increasing number of metabolic syndrome components were found to be associated with a higher SVRI, and obesity and hypertension remained independent determinants in the multivariable model in adults [10]. Additionally, other studies have found increased vascular resistance in hypertensive subjects [11] and individuals with abdominal obesity [12]. LDL cholesterol has also been associated with systemic vascular resistance cross-sectionally in adults [13]. The present study provides a novel life-long perspective in addition to previous adulthood cross-sectional findings, showing that childhood blood glucose and BMI were independently associated with the SVRI in the multivariable model, supporting the role of these traditional cardiovascular risk factors as determinants of vascular resistance. However, childhood blood glucose and BMI did not remain independent predictors of SVRI after further adjustment with corresponding adulthood data. Altogether, the present study adds to current

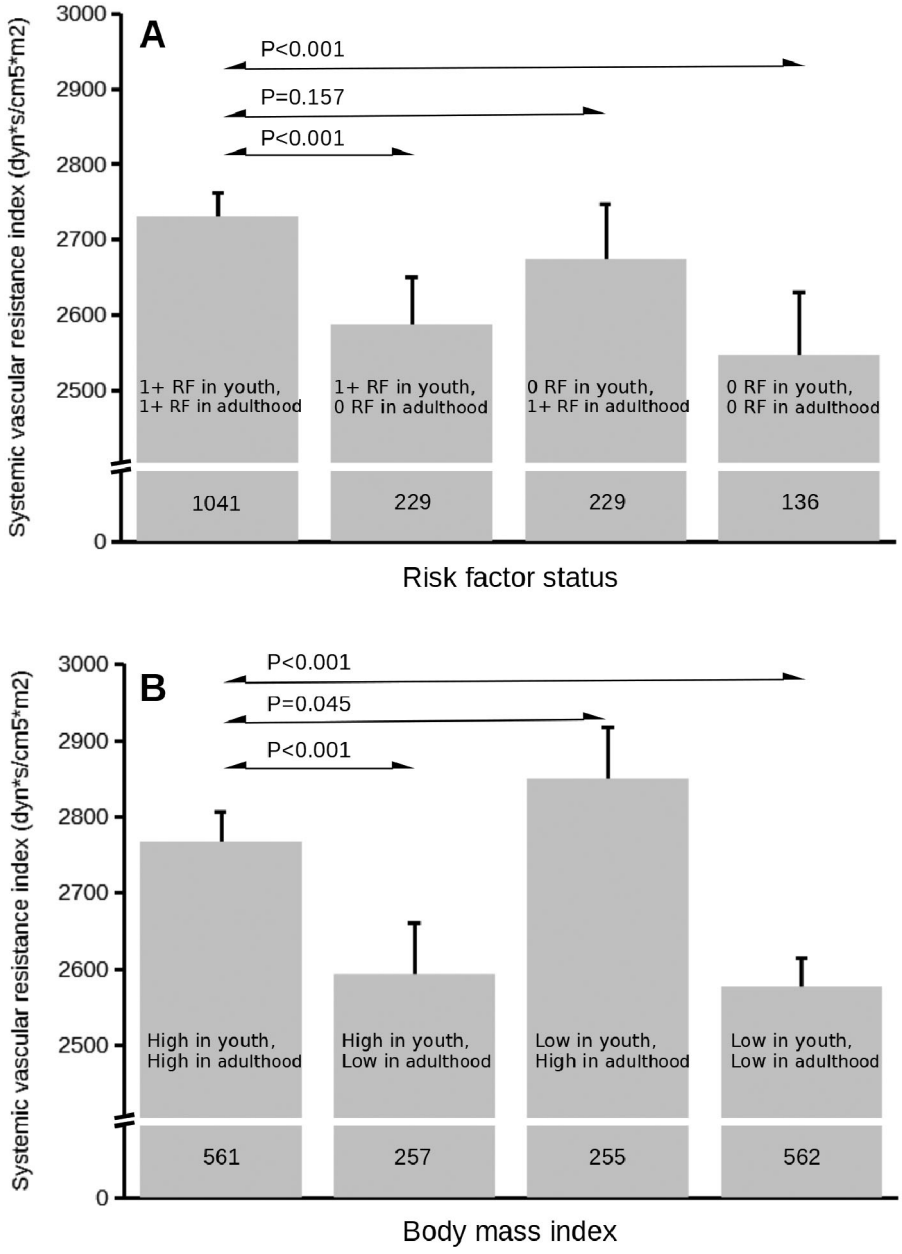

Figure 2. (A) Relations between the risk scores in childhood (ages 3–18 years) and adulthood (ages 24–45 years) and the SVRI in adulthood (2007). Subjects having 0 risk factors and unfavourable lifestyle factors were considered to have favourable status and those with $\geq$1 risk factor or unfavourable lifestyle factor were considered to have unfavourable status. (B) Relations between BMI in childhood (ages 3–18 years) and adulthood (ages 24–45 years) and the SVRI in adulthood (2007). A cut-off point of age- and sex-specific 50th percentile was used, classifying BMI as favourable or unfavourable status. *P*-values from *t* tests. Bars represent the mean plus the 95% confidence interval. Values inside columns indicate the number of subjects in each group.

knowledge by providing a lifetime risk factor and unfavourable lifestyle factor burden perspective in studying factors associated with adulthood small artery status.

Interestingly, childhood vegetable consumption was an independent lifestyle predictor of adulthood SVRI even after adjustment for adulthood vegetable consumption, suggesting that childhood vegetable consumption may have a favourable influence on small vessel status later in life. A previous study of the current cohort showed that a decreased frequency of childhood vegetable consumption predicted high adulthood blood pressure [26], a finding that is in concert with the present association observed between childhood vegetable consumption and adulthood SVRI. Thus, the present finding provides a novel hemodynamic mechanism behind the previously observed association of vegetable consumption and blood pressure [26]. Frequent vegetable consumption can be considered a conscious decision to make

healthy food choices, particularly in the 1980s. High levels of physical activity, vegetable consumption and abstaining from smoking may also be correlated and may correlate with other beneficial lifestyle choices not measured in the present study. Therefore, the association of childhood vegetable consumption with adulthood SVRI may merely reflect the effect of an overall healthier lifestyle during early life rather than represent significant confounding. High vegetable and fruit consumption is also included in the American Heart Association's ideal cardiovascular health goals, and the concept is also supported by the current findings.

Physical activity in childhood was also an independent predictor of the SVRI even after adjustment for adulthood physical activity, and higher physical activity was associated with a higher SVRI. Childhood physical activity was also an independent determinant of the CI with an inverse association. Exercise training is known to affect cardiac function by reducing resting heart rate *via* intrinsic electrophysiological changes in the sinus node [27]. Since the cardiac function and vascular resistance are tightly connected in the process of maintaining stable blood pressure, a higher SVRI associated with higher physical activity could simply be a reflection of a lower CI associated with physical activity.

The current study showed for the first time that childhood smoking was directly associated with adulthood SVRI, which could be the result of long-term microvascular structural or functional changes caused by childhood smoking. Interestingly, adulthood smoking status was inversely associated with the SVRI. Cross-sectionally, systemic vascular resistance has been shown to be lower in current smokers than in previous or never smokers in adults [14], a finding that is in agreement with the present finding. A pathophysiological mechanism behind this finding could be the direct and indirect hemodynamic influences of carbon monoxide in tobacco smoke, such as vasodilation [28].

The number of childhood risk factors and unfavourable lifestyle factors directly correlated with the adult SVRI even after additional adjustment with the corresponding adulthood score. However, such an association was not consistently observed with the CI. Interestingly, a favourable change in the number of risk factors and unfavourable lifestyle factors or a favourable change in BMI from childhood to adulthood was associated with a lower SVRI in adulthood. Thus, even though some risk factor and lifestyle factor associations with the CI were observed in the multivariable regression analysis, altogether, these findings suggest that lifetime changes in risk factor and lifestyle factor status appear to have a more consistent impact on vascular resistance than on cardiac output. The findings support the view that early intervention in childhood leading to an improved risk factor profile and lifestyle may lead to favourable vascular changes later in life.

In previous studies of the current cohort, we evaluated the association of childhood risk factors and lifestyle on adulthood large artery and structural and functional changes, such as carotid intima-media thickness (IMT) and its progression, carotid artery elasticity, and arterial pulse wave velocity [19,22]. Childhood physical activity (inverse association) and fruit consumption were significant predictors of 6-year changes in carotid IMT when adjusted with corresponding adulthood data [22]. Additionally, a number of childhood risk factors and changes in the HDL/LDL ratio and BMI were associated with 6-year changes in IMT [22]. Childhood systolic blood pressure and blood glucose [29] and childhood systolic blood pressure, vegetable consumption, and BMI [19] were independent predictors of adulthood arterial pulse wave velocity. However, these associations were not adjusted with corresponding adulthood data. For carotid artery elasticity, independent childhood risk factor predictors were obesity (skinfold thickness), systolic blood pressure and childhood risk factor score, with the latter two remaining significant after adjustment for current risk factors [30]. Altogether, childhood risk factors and lifestyle factors independently associated with large artery structural and functional changes were partially similar when compared with the current findings concerning the SVRI. Remarkable differences in risk factor and lifestyle factor associations were also observed, especially lifetime lifestyle associations of physical activity and smoking on adulthood SVRI, which appear to considerably differ from the associations observed with large artery structure and function. Thus, the present findings significantly expand current knowledge regarding the influences of childhood risk factors and lifestyle on cardiovascular health. Interestingly, for example high childhood BMI has also been shown to be associated with increased risk of coronary heart disease in adulthood [31], and obesity, glucose intolerance, and hypertension in childhood have been reported to be strongly associated with increased rates of premature death to endogenous causes in adulthood [32], supporting the concept of maintaining optimal childhood

cardiovascular risk factors levels in the primary prevention of diseases later in life.

The chief determinant of vascular resistance is microcirculation since it presents the greatest resistance to blood flow [33,34]. Thus, the influence of risk factors and lifestyle factors on the mechanisms affecting the radius of the small resistance arteries could be potential pathophysiological mechanisms behind the current findings. One such mechanism could be endothelial dysfunction caused by cardiovascular risk factors such as elevated blood pressure [35,36]. Since an increased media-to-lumen ratio of small resistance arteries has been found in hypertension [37], microvascular structural changes caused by lifetime risk factors and unfavourable lifestyle burden could also be one potential mechanism behind the findings of the current study.

The strength of our study is the large, randomly selected cohort of young adults followed for 27 years since childhood. Since non-invasive hemodynamic measurement findings should be interpreted cautiously in general, one of the limitations of the present study is the measurement method used. However, the current method is well validated, and the stroke volume and cardiac output values are in agreement with the values measured by the invasive thermodilution method and 3-dimensional echocardiography [23–25]. The repeatability of cardiac output measurements by the impedance method has been reported to be even better than that by the thermodilution method [23]. Hence, the present method is suitable for the evaluation of systemic hemodynamics in an epidemiological study setting. Our study cohort was ethnically rather homogenous, consisting solely of white European subjects. 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.

The present study has demonstrated that childhood BMI, blood glucose, vegetable consumption, smoking, and physical activity independently predict systemic vascular resistance in adulthood, and a favourable change in the number of risk factors or favourable change in BMI from childhood to adulthood was associated with lower vascular resistance in adulthood.

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