Arterial Intima-Media Thickness, Endothelial Function, and Apolipoproteins in Adolescents Frequently Exposed to Tobacco Smoke

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Background—Exposure to tobacco smoke is associated with markers of preclinical atherosclerosis in adults, but its effect on arterial structure in adolescents is unknown.

Methods and Results—Healthy 13-year-old adolescents from the atherosclerosis prevention trial STRIP were studied. Maximum carotid and aortic intima-media thickness and brachial artery flow-mediated dilation were measured in 494 adolescents using high-resolution ultrasound. Serum lipid, lipoprotein, and apolipoprotein (Apo) A-I and B concentrations were determined using standard methods. Exposure to tobacco smoke was measured annually between ages 8 and 13 years using serum cotinine concentrations, analyzed with gas chromatography. To define longitudinal exposure, cotinine values of children having serum cotinine measured 2 to 6 times during follow-up were averaged and divided into tertiles (exposure groups): low (n=160), intermediate (n=171), and high (n=163). Adolescents with higher longitudinal exposure to tobacco smoke had increased carotid intima-media thickness (exposure groups [mean±SD]: low, 0.502±0.079 mm; intermediate, 0.525±0.070 mm; high, 0.535±0.066 mm; P<0.001) and increased aortic intima-media thickness (exposure groups: low, 0.527±0.113 mm; intermediate, 0.563±0.139 mm; high, 0.567±0.126 mm; P=0.008). The flow-mediated dilation decreased when cotinine level increased (exposure groups: low, 10.43±4.34%; intermediate, 9.78±4.38%; high, 8.82±4.14%; P=0.004). Moreover, ApoB (P=0.014) and ApoB/ApoA-I ratio (P=0.045) increased with increase in cotinine level. The associations between tobacco smoke exposure and ultrasound variables were unchanged after adjusting for traditional atherosclerosis risk factors and for ApoB.

Conclusions—Frequent exposure to tobacco smoke is independently associated with arterial changes of preclinical atherosclerosis and increased ApoB levels among healthy adolescents.

Clinical Trial Registration—clinicaltrials.gov. Identifier: NCT00223600.

(Circ Cardiovasc Qual Outcomes. 2010;3:196-203.)

Key Words: apolipoproteins ■ atherosclerosis ■ passive smoking ■ pediatrics ■ vasodilation

Exposure to tobacco smoke causes vascular damage by multiple mechanisms. Passive smoking has been associated with attenuated endothelium-dependent dilation in young healthy adults. We have previously shown in 11-year-old healthy children that tobacco smoke exposure is associated with endothelial dysfunction measured by flow-mediated dilation (FMD) of the brachial artery. In addition, both past and current passive smoking has been related with increased carotid intima-media thickness (cIMT) in adults. Moreover, tobacco smoke exposure in pregnancy has recently been associated with increased aortic intima-media thickness (aIMT) in neonates and increased cIMT in young adolescents. Conventional cardiovascular risk factors have been related to early structural vascular wall changes in childhood and exposure to cardiovascular risk factors in adolescence predicts increased adult cIMT. However, none of the previous studies has examined the impact of exposure to tobacco smoke on IMT in healthy children or adolescents.

Exposure to tobacco smoke may lead to alterations in serum lipid profile, especially to decrease in HDL cholesterol, in children and adolescents. In adults, heavy workplace exposure to tobacco smoke has been demonstrated to have an adverse influence on serum lipids. Recently, it was indicated that maternal smoking in pregnancy is associ-
ated with an increase in total cholesterol levels and trends toward adverse lipoprotein profiles in the young adult offspring. However, there are no data on the relations of exposure to tobacco smoke and apolipoprotein (Apo) levels in children or adolescents.

In addition to vascular ultrasound measurements, study children’s serum lipid, lipoprotein, and Apo values, as well as dietary intakes, somatic growth and pubertal development have been well documented in the prospective, randomized Special Turku Coronary Risk Factor Intervention Project (STRIP). Exposure to tobacco smoke as indicated by objective measurement, serum cotinine concentration, has been frequently determined in school-aged children. The aim of the present study was to examine the effects of frequent exposure to tobacco smoke on vascular wall structure, endothelial function, and serum lipid profile in healthy 13-year-old adolescents.

WHAT IS KNOWN

- Exposure to environmental tobacco smoke is related to increased carotid intima-media thickness in adults, but this association has not been studied in children.
- Exposure to environmental tobacco smoke may lead to alterations in serum lipid profile, but there are no data on the relations of tobacco smoke exposure and apolipoprotein levels in children.

WHAT THE STUDY ADDS

- This study shows that frequent exposure to environmental tobacco smoke is associated with increased carotid and abdominal aortic intima-media thickness and increased apolipoprotein B levels among healthy 13-year-old adolescents.

Methods

Study Design

The STRIP project is a randomized, prospective intervention trial aimed at decreasing the exposure of children to known environmental cardiovascular risk factors. As described, voluntary families of 5-month-old infants were recruited in 1990 through 1992 at the well-baby clinics in the city of Turku, Finland. At the age of 7 months, 1062 infants were randomly assigned to an intervention group (n=540) or to a control group (n=522). The intervention families received individualized and detailed dietary and lifestyle counseling biannually. Dietary intervention aimed at achieving a fat intake of 30% to 35% of daily energy (E%), with a ratio of saturated to (monounsaturated plus polyunsaturated) fatty acid of 1:2. After the age of 9 years, the prevention of onset of smoking was introduced to the children of the intervention group. The control children received no detailed dietary counseling or smoking prevention. The age of 9 years, the prevention of onset of smoking was introduced to the children of the intervention group. The control children received no detailed dietary counseling or smoking prevention. The growth, development, and well-being of all children were carefully followed up at 6- to 12-month intervals. Food consumption data were obtained through annual 4-day food records. The nutrient intakes were calculated with software (Micro Nutrica, Turku, Finland), based on the Food and Nutrient Database of the Social Insurance Institution. Venous blood samples were drawn yearly after an overnight fast, except at age 8, when the samples were nonfasting. The study protocol was approved by the local ethics committee. Informed consent was obtained from the parents.

Subjects

Study children’s serum cotinine concentrations were determined annually from every obtained blood sample between the ages 8 and 13 years. To define children’s longitudinal exposure to tobacco smoke, serum cotinine values of the children with cotinine values available 2 to 6 times between the ages 8 and 13 years were averaged (arithmetic mean per each child) for the analyses. Study children were then divided into tertiles according these averaged cotinine values. At the age of 13 years, the number of the adolescents was 545 (98% of the participating age cohort), and the majority of the subjects (93%) had cotinine values available 5 or 6 times during the follow-up.

Of the 545 adolescents with longitudinal cotinine measurements, 494 (91%) had appropriate ultrasound measurements available at the age of 13 years: cIMT measurements were available in 494, aIMT measurements in 487, and brachial artery measurements in 482 adolescents. Of the 494 study subjects with ultrasound data, 163 belonged to the high tobacco smoke exposure group (the highest tertile of averaged cotinine values), 171 to the intermediate exposure group (the midmost tertile), and 160 to the low exposure group (the lowest tertile of averaged cotinine concentrations). Children with serum cotinine concentration >15 ng/mL were defined as active smokers and were excluded from all analyses. Number of active smokers was 1 and 5 in 10- and 13-year-old children, respectively.

Background Data

Data on maternal smoking in pregnancy was collected retrospectively from the delivery records of the mothers. Other background data were collected at age 13, that is, at the same age as the ultrasound measurements. Weight was measured using an electronic scale to the nearest 0.1 kg (Soehnle S10; Soehnle, Murrhardt, Germany) and height to the nearest 0.1 cm, using a Harpenden stadiometer (Hol lain, Crym ych, United Kingdom), and the body mass index (BMI) was calculated as kilograms per meter squared. Children’s sexual maturation was determined using Tanner staging, and adolescents were classified either late pubertal (Tanner stage M/G ≥3) or early pubertal (M/G 1 to 2).

Laboratory Methods

Serum lipid and apolipoprotein determinations have been described in detail. Serum cholesterol concentration was measured with a fully enzymatic cholesterol oxidase-p-aminophenazone method (CHOD-PAP; Merck, Darmstadt, Germany). Serum HDL cholesterol concentration was measured after precipitation of LDL and VLDL with dextran sulfate 500 000. ApoA-I and ApoB were determined immunoturbidimetrically (Orion Diagnostica, Espoo, Finland). The interassay (intra-assay) coefficients of variation (CV) for total cholesterol, HDL, ApoA-I, and ApoB were 2.0% (1.5%), 1.9% (1.2%), 3.0% (1.8%), and 4.5% (3.3%), respectively. Serum triglyceride values were measured with the colorimetric GPO-PAP method (Merck, Darmstadt, Germany). Serum LDL cholesterol values were calculated using the Friedewald formula.

Serum high-sensitivity C-reactive protein concentrations were assayed using the immunoturbidimetric method, as described. Cotinine was extracted into dichloroethane from 0.2 mL of serum, to which 0.2 mL of 5-methylcitocine (0.1 μg/mL in 0.01 mol/L HCl) was added by the method of Feyerabend and Russell. Concentrated extract (2.0 μL) was injected into a Hewlett Packard FFAP silica capillary column (Agilent Technologies, Palo Alto, Calif) of the Shimadzu model GC-17 gas chromatograph (Shimadzu, Kyoto, Japan), equipped with a nitrogen-sensitive flame-thermionic detector. The analytic sensitivity of the method was 0.16 ng/mL. The intra-assay and interassay CVs at a cotinine concentration of 22 ng/mL were 4.4% and 11.7%, respectively. The interassay CV at a cotinine concentration of 1 ng/mL was 23.3%.

Ultrasound Measurements

An Acuson Sequoia 512 ultrasound mainframe (Acuson, Mountain View, Calif) with a 13.0-MHz linear-array transducer was used. The
ultrasound scanning and the off-line analysis of the scans were performed by a single experienced sonographer blinded for the participant data as described. Blood pressure was measured after 10 minutes of rest with an automated sphygmomanometer (Omron M4; Omron Matsusaka, Matsusaka, Japan) from the right arm three times, and the readings were averaged for the analyses. For the cIMT measurements, the far (posterior) wall of the distal common carotid arteries 1 to 2 cm from the bulb on both sides was scanned from anterior oblique and lateral angles. Several images of the common carotid arteries 1 to 2 cm from the bulb on both sides was scanned, and the image was magnified using a resolution box function. Several images were focused on the far wall (dorsal arterial wall). Images 15 mm in width of the abdominal aorta wall was scanned, and the image was stored for subsequent offline analysis. Two end-diastolic frames from both interrogation angles were acquired. Two end-diastolic frames from both interrogation angles were analyzed for IMTs. Maximum cIMT and the average of these measurements as mean cIMT were used. In our study, the interobserver CV of cIMT measurements was 3.0%. The interobserver CV in aIMT measurements was 2.9%. The aIMT was studied as described. Briefly, the most distal part of the abdominal aorta was scanned and the image was focused on the far wall (dorsal arterial wall). Images 15 mm in width were magnified using a resolution box function. Several images were taken at end-diastole and stored for subsequent offline analysis. Two end-diastolic frames from both interrogation angles were analyzed for IMTs. Maximum aIMT and the average of these measurements as mean aIMT were used. The interobserver CV in cIMT measurements was 3.0%, and the between-visits variation (CV) was 3.9%. The aIMT was studied as described. 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Increased flow was then induced by inflation of an adult-size blood pressure cuff around the forearm to a pressure of 250 mm Hg for 4.5 minutes, followed by release. A second scan was taken continuously 40 to 180 seconds after cuff deflation. The percentual dilation from baseline in 10-second intervals was assessed. From these data, peak FMD was determined. The interobserver CV of FMD measurements was 8.6%, and the between-study CV was 9.3%. Statistical Methods Variables with skewed distribution were log-transformed for the analyses. Results are expressed as mean (standard deviation) or geometric mean (95% CI). Blood pressure was measured after 10 minutes of rest with an automated sphygmomanometer (Omron M4; Omron Matsusaka, Matsusaka, Japan) from the right arm three times, and the readings were averaged for the analyses. For the cIMT measurements, the far (posterior) wall of the distal common carotid arteries 1 to 2 cm from the bulb on both sides was scanned from anterior oblique and lateral angles. Several images of the common carotid artery far wall segment of 10 mm in width were acquired. Two end-diastolic frames from both interrogation angles were analyzed for IMTs. Maximum cIMT and the average of these measurements as mean cIMT were used. In our laboratory, the interobserver CV of cIMT measurements was 3.0%, and the between-visits variation (CV) was 3.9%. The aIMT was studied as described. Briefly, the most distal part of the abdominal aorta was scanned, and the image was focused on the far wall (dorsal arterial wall). Images 15 mm in width were magnified using a resolution box function. Several images were taken at end-diastole and stored for subsequent offline analysis. Two images of the best quality were chosen for analysis in each study subject. Using ultrasonic calipers, at least 4 to 6 IMT measurements were taken at end-diastole and stored for subsequent offline analysis. Two images of the best quality were chosen for analysis in each study subject. Using ultrasonic calipers, at least 4 to 6 IMT measurements covering the entire far wall segment of interest were taken for each image. Maximum aIMT and the average of these measurements as mean aIMT were used. The interobserver CV in aIMT measurements was 3.0%, and the between-visits CV was 4.9%. As described, left brachial artery diameter was measured from B-mode ultrasound images at rest and during reactive hyperemia. Briefly, a resting scan was performed and arterial flow velocity was measured using a Doppler signal. Increased flow was then induced by inflation of an adult-size blood pressure cuff around the forearm to a pressure of 250 mm Hg for 4.5 minutes, followed by release. A second scan was taken continuously 40 to 180 seconds after cuff deflation. The percentual dilation from baseline in 10-second intervals was assessed. From these data, peak FMD was determined. The interobserver CV of FMD measurements was 8.6%, and the between-study CV was 9.3%.

### Table 1. Characteristics of 13-Year-Old Adolescents in 3 Longitudinal Tobacco Smoke Exposure Groups

<table>
<thead>
<tr>
<th>Longitudinal Exposure to Tobacco Smoke†</th>
<th>ANOVA P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Averaged serum cotinine, ng/mL∗</td>
<td>0.28 (0.27–0.29)</td>
</tr>
<tr>
<td>No. of subjects</td>
<td>160</td>
</tr>
<tr>
<td>Boys, %</td>
<td>51</td>
</tr>
<tr>
<td>In STRIP intervention group, %‡</td>
<td>56</td>
</tr>
<tr>
<td>Late pubertal, %§</td>
<td>81</td>
</tr>
<tr>
<td>Maternal smoking in pregnancy, %</td>
<td>5</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>19.3±3.1</td>
</tr>
<tr>
<td>Total cholesterol, mmol/L</td>
<td>4.16±0.73</td>
</tr>
<tr>
<td>HDL cholesterol, mmol/L</td>
<td>1.21±0.24</td>
</tr>
<tr>
<td>LDL cholesterol, mmol/L</td>
<td>2.60±0.63</td>
</tr>
<tr>
<td>Triglycerides, mmol/L†</td>
<td>0.73 (0.68–0.78)</td>
</tr>
<tr>
<td>ApoB, g/L</td>
<td>0.73±0.17</td>
</tr>
<tr>
<td>ApoA-I, g/L</td>
<td>1.34±0.20</td>
</tr>
<tr>
<td>ApoB/ApoA-I</td>
<td>0.56±0.15</td>
</tr>
<tr>
<td>hsCRP, mg/L</td>
<td>0.31 (0.27–0.37)</td>
</tr>
<tr>
<td>Fat intake, %E</td>
<td>31.0±5.2</td>
</tr>
<tr>
<td>Saturated fat intake, %E</td>
<td>12.1±2.9</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>107±8</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>61±4</td>
</tr>
<tr>
<td>Brachial artery baseline diameter, mm</td>
<td>2.9±0.3</td>
</tr>
</tbody>
</table>

Values are mean±SD, unless otherwise indicated.
hsCRP indicates high-sensitivity C-reactive protein.
∗Geometric mean (95% CI) of the averaged 2 to 6 serum cotinine measurements between the ages 8 and 13 years.
†Groups are formed by dividing averaged serum cotinine values into tertiles.
‡For details, see study design.
§Proportion of children in late puberty (Tanner stage M/G ≥3).
||Geometric mean (95% CI), logarithmic transformation used in statistical analyses.
### Results

Characteristics of 13-year-old adolescents in the tobacco smoke exposure groups are shown in Table 1. Averaged serum cotinine values ranged from 0.1 to 0.4 ng/mL in the low exposure group, from 0.4 to 0.7 ng/mL in the intermediate group, and from 0.7 to 4.1 ng/mL in the high exposure group. ApoB values (ANOVA $P=0.014$; difference between groups, 0.057 g/L, $P=0.011$) and ApoB/ApoA-I ratio (ANOVA $P=0.045$; difference, 0.042, $P=0.039$) were increased in the highest cotinine level group compared with the lowest. Diastolic blood pressure ($P=0.006$) and BMI ($P=0.022$) differed between exposure groups (Table 1).

In 1-way ANOVA, maximum cIMT increased already with intermediate tobacco smoke exposure ($P<0.001$) (Table 2 and Figure 1). The relation was essentially similar when mean cIMTs were used instead of maximum values ($P<0.001$). In line, adolescents with even intermediately increased exposure to tobacco smoke had higher maximum aIMT ($P=0.008$) (Table 2 and Figure 1). In addition, mean aIMT increased with increasing exposure ($P=0.027$). Endothelial function was decreased in the highest exposure group compared with the lowest ($P=0.004$) (Table 2 and Figure 2).

The maximum cIMT was associated with systolic and diastolic blood pressure, total and LDL cholesterol, ApoB, ApoA-I, and sex (greater in boys) (Table 3). The maximum aIMT was associated with BMI, diastolic blood pressure, triglycerides, ApoB, ApoB/ApoA-I ratio, and high-sensitivity C-reactive protein, whereas endothelial function showed no significant associations with the established risk factors.

### Table 2. Associations Between Tobacco Smoke Exposure Groups (Low, Intermediate, High) and Maximum cIMT, aIMT, and Peak FMD

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted Mean ± SE</th>
<th>1-Way ANOVA $P$</th>
<th>Adjusted Mean ± SE*</th>
<th>Multivariable ANCOVA $P$*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum cIMT, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low exposure</td>
<td>0.502 ± 0.006</td>
<td></td>
<td>0.505 ± 0.006</td>
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<tr>
<td>Intermediate</td>
<td>0.525 ± 0.005</td>
<td>&lt;0.001</td>
<td>0.526 ± 0.005</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>High exposure</td>
<td>0.535 ± 0.006</td>
<td></td>
<td>0.535 ± 0.006</td>
<td></td>
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<tr>
<td>Maximum aIMT, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low exposure</td>
<td>0.527 ± 0.010</td>
<td></td>
<td>0.527 ± 0.010</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>0.563 ± 0.010</td>
<td>0.008</td>
<td>0.561 ± 0.009</td>
<td>0.002</td>
</tr>
<tr>
<td>High exposure</td>
<td>0.567 ± 0.010</td>
<td></td>
<td>0.573 ± 0.010</td>
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<tr>
<td>Peak FMD, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low exposure</td>
<td>10.43 ± 0.35</td>
<td></td>
<td>10.43 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>9.78 ± 0.33</td>
<td>0.004</td>
<td>9.78 ± 0.33</td>
<td>0.004</td>
</tr>
<tr>
<td>High exposure</td>
<td>8.82 ± 0.34</td>
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<td>8.82 ± 0.34</td>
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Pairwise Comparison

<table>
<thead>
<tr>
<th></th>
<th>Difference ± SE</th>
<th>$P$†</th>
<th>Adjusted Difference ± SE*</th>
<th>$P$†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum cIMT, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low vs intermediate</td>
<td>-0.023 ± 0.008</td>
<td>0.013</td>
<td>-0.021 ± 0.008</td>
<td>0.018</td>
</tr>
<tr>
<td>Low vs high</td>
<td>-0.033 ± 0.008</td>
<td>&lt;0.001</td>
<td>-0.031 ± 0.008</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intermediate vs high</td>
<td>-0.010 ± 0.008</td>
<td>0.57</td>
<td>-0.009 ± 0.008</td>
<td>0.70</td>
</tr>
<tr>
<td>Maximum aIMT, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low vs intermediate</td>
<td>-0.036 ± 0.014</td>
<td>0.032</td>
<td>-0.035 ± 0.013</td>
<td>0.026</td>
</tr>
<tr>
<td>Low vs high</td>
<td>-0.041 ± 0.014</td>
<td>0.013</td>
<td>-0.047 ± 0.014</td>
<td>0.002</td>
</tr>
<tr>
<td>Intermediate vs high</td>
<td>-0.005 ± 0.014</td>
<td>&gt;0.99</td>
<td>-0.012 ± 0.013</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>Peak FMD, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low vs intermediate</td>
<td>0.65 ± 0.48</td>
<td>0.52</td>
<td>0.65 ± 0.48</td>
<td>0.52</td>
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<tr>
<td>Low vs high</td>
<td>1.61 ± 0.49</td>
<td>0.003</td>
<td>1.61 ± 0.49</td>
<td>0.003</td>
</tr>
<tr>
<td>Intermediate vs high</td>
<td>0.96 ± 0.47</td>
<td>0.13</td>
<td>0.96 ± 0.47</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*All models include sex, STRIP study group, pubertal status, BMI, and diastolic blood pressure as covariates. The cIMT analysis also includes ApoB, ApoA-I, LDL cholesterol, and FMD. The aIMT analysis also includes triglycerides, ApoB/ApoA-I, high-sensitivity C-reactive protein, maternal smoking in pregnancy, and FMD. The FMD analysis also includes ApoB.

†Pairwise comparison with post hoc Bonferroni procedure.
In ANCOVA, after adjusting for all related covariates, the cotinine exposure level remained as a significant predictor for maximum cIMT (P<0.001), maximum aIMT (P=0.002), and peak FMD (P=0.004) (Table 2). Table 2 also shows that least-squares means in ANOVA and in multivariable ANCOVA models were almost identical suggesting that the effect of tobacco smoke exposure on vascular changes was not mediated through covariates.

In ANCOVA of lipid variables, after adjusting for sex, STRIP study group, pubertal status, diastolic blood pressure, and BMI, the longitudinal tobacco smoke exposure remained in the final model of ApoB (P=0.022) and ApoB/ApoA-I ratio (P=0.032).

All associations between longitudinal tobacco smoke exposure and aforementioned response variables were unchanged when analyses were restricted to the children with serum cotinine values available in at least 5 of the possible 6 measures during follow-up (data not shown).

**Discussion**

The present study demonstrates that healthy 13-year-old adolescents with frequent exposure to tobacco smoke during the ages 8 and 13 years have significantly increased IMT both in distal abdominal aorta and in carotid arteries. Importantly, the present study suggests that even modest exposure to tobacco smoke is associated with increased IMT. As thickness of the arterial wall is a marker of early atherosclerosis, our data suggest that exposure to tobacco smoke may play a role in the development of atherosclerosis.

Previously, there were no studies in healthy children or adolescents of the association between second-hand smoke exposure and endothelial dysfunction in children and young adults. The present results confirm our previous findings reported in 11-year-old children. We continue to see that tobacco smoke exposure has a strong inverse relation with FMD responses in this cohort as the children mature. Endothelial dysfunction may be the first phenomenon in subclinical atherosclerosis preceding the thickening of the vascular wall. Interestingly, despite the clear association between altered endothelial function and passive smoking in these adolescents, the association between IMT and smoke exposure was virtually unchanged after controlling for FMD. The potential mechanisms by which exposure to tobacco smoke increases IMT may comprise direct toxic effects of cigarette smoke constituents on endothelial permeability and structure, enhanced platelet activity that they will bind to injured areas and promote growth of smooth muscle cells, and increased lipid peroxidation in combination with accelerated uptake of LDL cholesterol by macrophages.

We found that exposure to tobacco smoke was associated with increased ApoB and ApoB/ApoA-I ratio. To our knowledge, there are no previous reports in children or adolescents of the association of tobacco smoke exposure and apolipoproteins. The concentration of ApoB provides a direct measure of the number of circulating atherogenic lipoproteins, and the ApoB/ApoA-I ratio represents the balance of proatherogenic and antiatherogenic lipoproteins. Childhood levels of ApoB/ApoA-I ratio predict cIMT and endothelial function in adulthood. In middle-aged adults, ApoB/ApoA-I ratio is related to change in cIMT and is a strong predictor of coronary events. Thus, ApoB/ApoA-I ratio may be the best single lipoprotein variable related to coronary risk.
Explanatory Variable | Regression Coefficient ß ± SE | P | Regression Coefficient ß ± SE | P | Regression Coefficient ß ± SE | P
--- | --- | --- | --- | --- | --- | ---
Male sex* | 0.030 ± 0.006 | <0.001 | 0.004 ± 0.012 | 0.70 | −0.338 ± 0.395 | 0.39
STRIP control group† | −0.010 ± 0.007 | 0.12 | −0.002 ± 0.012 | 0.85 | 0.127 ± 0.395 | 0.75
Late puberty* | 0.003 ± 0.008 | 0.73 | 0.013 ± 0.014 | 0.34 | 0.285 ± 0.484 | 0.56
Maternal smoking in pregnancy* | −0.004 ± 0.013 | 0.77 | 0.039 ± 0.022 | 0.080 | −0.087 ± 0.773 | 0.91
BMI, kg/m² | 0.001 ± 0.001 | 0.33 | 0.016 ± 0.002 | <0.001 | 0.042 ± 0.063 | 0.50
Total cholesterol, mmol/L | −0.017 ± 0.004 | <0.001 | −0.002 ± 0.008 | 0.79 | 0.223 ± 0.272 | 0.41
HDL cholesterol, mmol/L | −0.019 ± 0.014 | 0.17 | −0.021 ± 0.025 | 0.40 | −0.270 ± 0.834 | 0.75
LDL cholesterol, mmol/L | −0.019 ± 0.005 | <0.001 | −0.008 ± 0.009 | 0.40 | 0.202 ± 0.315 | 0.52
Triglycerides, mmol/L‡ | −0.012 ± 0.008 | 0.13 | 0.042 ± 0.014 | 0.003 | 0.635 ± 0.474 | 0.18
ApoB, g/L | −0.032 ± 0.018 | 0.086 | 0.058 ± 0.033 | 0.081 | 0.808 ± 1.117 | 0.47
ApoA-I, g/L | −0.053 ± 0.017 | 0.002 | −0.021 ± 0.030 | 0.48 | 0.380 ± 1.013 | 0.71
ApoB/ApoA-I | 0.002 ± 0.022 | 0.93 | 0.079 ± 0.039 | 0.044 | 0.345 ± 1.306 | 0.79
hsCRP, mg/L‡ | 0.005 ± 0.003 | 0.12 | 0.024 ± 0.006 | <0.001 | −0.013 ± 0.200 | 0.95
Saturated fat intake, E% | −0.0001 ± 0.001 | 0.90 | 0.002 ± 0.002 | 0.45 | 0.016 ± 0.070 | 0.82
Systolic blood pressure, mm Hg | 0.002 ± 0.0004 | <0.001 | 0.001 ± 0.001 | 0.12 | −0.020 ± 0.024 | 0.42
Diastolic blood pressure, mm Hg | 0.003 ± 0.001 | <0.001 | 0.002 ± 0.001 | 0.041 | 0.040 ± 0.041 | 0.34

hsCRP indicates high-sensitivity C-reactive protein.
*Regression coefficient indicates difference between group means.
†For details, see study design.
‡Logarithmic transformation.
§All relations were essentially similar when mean IMTs were used instead of maximum IMTs.

The underlying mechanisms for how smoke exposure influences lipid metabolism are not clearly elucidated. However, cigarette smoking has been shown to increase hepatic lipase activity, which inhibits cholesterol acyl-transferase activity, and decreases lipoprotein lipase activity. In nicotine-treated rats, increased synthesis and secretion of ApoB containing lipoproteins was found. These findings suggest that nicotine exerts hyperlipidemic effects, particularly by increasing the synthesis and secretion of triglyceride-rich lipoproteins. Many effects of passive smoking occur at very low exposure levels, as the majority of the environmental tobacco smoke is sidestream smoke, containing many toxic substances in higher concentrations than in mainstream smoke, due to different combustion conditions.

It is noteworthy that C-reactive protein, the inflammatory marker related to atherosclerosis, was similar across the cotinine groups, indicating that mechanisms other than the induction of systemic inflammation probably contribute to the association between exposure to tobacco smoke and vascular changes in adolescents. Other known causes of vascular damage presumably did not affect the main findings, as the tobacco smoke exposure groups predominantly did not differ in terms of atherosclerotic risk factors, or appropriate adjustments were performed.

The major strengths of the present study were the large sample size of nearly 500 adolescents, and the longitudinal design with frequent cotinine measurements during exposure to tobacco smoke. Uniquely, this objective biomarker of tobacco smoke exposure was available in most of the children 5 to 6 times between the ages 8 and 13 years. As children's cotinine concentrations clearly fluctuated during follow-up, annually measured cotinine values were averaged for the analyses and children were divided into tertiles. Thus, these 3 longitudinal exposure groups present different levels of tobacco smoke exposure during follow-up reasonably well. Overall, the exposure levels of these study children were only moderate. For example, assuming that an average active smoker with consumption of 20 cigarettes a day derives a cotinine concentration of 300 ng/mL in blood, the nicotine intake of these adolescents in the 3 longitudinal tobacco smoke exposure groups was equivalent to the active smoking of approximately 7, 12, and 27 cigarettes per year, respectively.

We acknowledge that serum cotinine concentration is not a measure of past exposure because it reflects the exposure to tobacco smoke during the past few days. However, there are no methods available to objectively quantify long-term exposure to tobacco smoke. Moreover, our longitudinal study design to some extent reflects children's long-term exposure.
to tobacco smoke. Lack of data on smoke exposure of the study children before the age of 8 years is another limitation of the present study. We excluded all children with high serum cotinine concentrations from the analyses to preclude active smoking. However, the possibility of intermittent or mild active smoking among study adolescents cannot definitively be excluded.

In summary, frequent exposure to tobacco smoke in childhood and adolescence may worsen the risk profile for later atherosclerosis by multiple mechanisms, as antecedent tobacco smoke exposure is unfavorably affecting carotid and aortic intima-media thickness, brachial artery endothelial function, and serum ApoB and ApoB/ApoA-I ratio levels among healthy 13-year-old adolescents. These data thus emphasize the importance of endorsing smoke-free environments for children and adolescents.

Acknowledgments

We thank Marja-Leena Toukkari (Joint Clinical Biochemistry Laboratory of University of Turku, Turku University Central Hospital and Vallac) and Anni Pakarinen (Research Centre of Applied and Preventive Cardiovascular Medicine) for their support in gathering data.

Sources of Funding

This study was supported by Finnish Cardiovascular Research Foundation; Academy of Finland (grants 34316, 73583, 64/2003); Sigrid Juselius Foundation; Specified Government Transfer, Turku University Hospital; Yrjö Jahnsson Foundation; Juho Vainio Foundation; Finnish Cultural Foundation; Regional Fund of Southwestern Finland of the Finnish Cultural Foundation; Foundation for Pediatric Research; Turku University Foundation; Finnish Medical Foundation; and Research Foundation of Orion Corporation, Finland.

Disclosures

None.

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Arterial Intima-Media Thickness, Endothelial Function, and Apolipoproteins in Adolescents Frequently Exposed to Tobacco Smoke
Katriina Kallio, Eero Jokinen, Maiju Saarinen, Mauri Hämäläinen, Iina Volanen, Tuuli Kaitosaari, Tapani Rönne, Jorma Viikari, Olli T. Raitakari and Olli Simell

Circ Cardiovasc Qual Outcomes. 2010;3:196-203; originally published online March 2, 2010; doi: 10.1161/CIRCOUTCOMES.109.857771

Circulation: Cardiovascular Quality and Outcomes is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-7705. Online ISSN: 1941-7713

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