BACKGROUND: Although public health programs have led to a substantial decrease in the prevalence of tobacco smoking, the adverse health effects of tobacco smoke exposure are by no means a thing of the past. In the United States, 4 of 10 school-aged children and 1 of 3 adolescents are involuntarily exposed to secondhand tobacco smoke (SHS), with children of minority ethnic backgrounds and those living in low-socioeconomic-status households being disproportionately affected (68% and 43%, respectively). Children are particularly vulnerable, with little control over home and social environment, and lack the understanding, agency, and ability to avoid SHS exposure on their own volition; they also have physiological or behavioral characteristics that render them especially susceptible to effects of SHS. Side-stream smoke (the smoke emanating from the burning end of the cigarette), a major component of SHS, contains a higher concentration of some toxins than mainstream smoke (inhaled by the smoker directly), making SHS potentially as dangerous as or even more dangerous than direct smoking. Compelling animal and human evidence shows that SHS exposure during childhood is detrimental to arterial function and structure, resulting in premature atherosclerosis and its cardiovascular consequences. Childhood SHS exposure is also related to impaired cardiac autonomic function and changes in heart rate variability. In addition, childhood SHS exposure is associated with clustering of cardiometabolic risk factors such as obesity, dyslipidemia, and insulin resistance. Individualized interventions to reduce childhood exposure to SHS are shown to be at least modestly effective, as are broader-based policy initiatives such as community smoking bans and increased taxation.

PURPOSE: The purpose of this statement is to summarize the available evidence on the cardiovascular health consequences of childhood SHS exposure; this will support ongoing efforts to further reduce and eliminate SHS exposure in this vulnerable population. This statement reviews relevant data from epidemiological studies, laboratory-based experiments, and controlled behavioral trials concerning SHS and cardiovascular disease risk in children. Information on the effects of SHS exposure on the cardiovascular system in animal and pediatric studies, including vascular disruption and platelet activation, oxidation and inflammation, endothelial dysfunction, increased vascular stiffness, changes in vascular structure, and autonomic dysfunction, is examined.

CONCLUSIONS: The epidemiological, observational, and experimental evidence accumulated to date demonstrates the detrimental cardiovascular consequences of SHS exposure in children.

IMPLICATIONS: Increased awareness of the adverse, lifetime cardiovascular consequences of childhood SHS may facilitate the development of innovative individual, family-centered, and community health interventions to reduce and ideally eliminate SHS exposure in the vulnerable pediatric population. This evidence calls for a robust public health policy that embraces zero tolerance of childhood SHS exposure.

Key Words: AHA Scientific Statement ■ atherosclerosis ■ blood vessels ■ child ■ tobacco smoke pollution

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Over the past 50 years, healthcare providers and public health professionals in the United States have increased awareness of the health risks associated with smoking tobacco. In 1964, ≈40% of adults in the United States were smokers, one third being women. 1 Although the percentage of US adults who smoke tobacco has decreased to an estimated 18%, >45 million US adults still smoke cigarettes, 2 with ≈500,000 dying each year of tobacco-smoke–related illnesses, and millions of children are involuntarily exposed to secondhand tobacco smoke (SHS) in the household or during transportation. 3 Recent reports from the Centers for Disease Control and Prevention show disparities in SHS between children and adults of different socioeconomic statuses (SESS). 3 Youth and adults of a lower SES have more SHS exposure than youth and adults of a higher SES. 3 Children 3 to 11 years old have the highest exposure to SHS, particularly children of minority ethnic backgrounds. Direct tobacco smoking in the United States has been estimated to result in $97 billion in medical costs annually, 4 and SHS exposure is reported to be associated with up to $6.6 billion in lost productivity each year. 5 Cigarette smoke is a potent atherosclerosis-promoting risk factor. Atherosclerosis can begin as early as the first decade of life and is often mediated by risk factors such as obesity, dyslipidemia, hypertension, and insulin resistance, in addition to history of tobacco use. 6,7 Several studies have also linked SHS exposure to accelerated atherosclerosis. 8–13

SHS is a mixture of gases and particles that emit from a burning tobacco product (eg, a cigarette, cigar, or pipe) or from smoke that has been exhaled by an individual actively smoking tobacco. 14,15 The scope of SHS exposure can span the life cycle, beginning in utero with exposure to maternal direct smoking or maternal SHS. SHS consists of hundreds of noxious particles, chemicals, and gases, including nicotine, total aerosol residue known as tar, which itself is composed of many volatile and semivolatile organic chemicals, carbon monoxide, ammonia, dimethylnitrosamine, formaldehyde, hydrogen cyanide, and acrolein. 16 Exposure to SHS is associated with an increased prevalence of respiratory infections, an increased frequency and severity of asthma exacerbations, and a greater risk of sudden infant death syndrome (SIDS). 14,17 Although the pulmonary consequences of SHS exposure are clinically apparent in childhood, the cardiovascular effects of SHS exposure are occult but long-lasting and substantial. Existing evidence suggests that SHS exposure in children and youth is detrimental to their cardiovascular health and that consequences attributable to SHS exposure may persist into adult life. 18 Although toxins in SHS-exposed environments are diluted compared with their concentration in inhaled (mainstream) smoke, some studies speculate that SHS exposure may as harmful as or more harmful to cardiovascular health than direct cigarette use because of longer exposure periods and persisting or evolving residual toxins than can promote inflammation, oxidative stress, and vascular dysfunction as SHS in the environment ages. 8,19–21 Furthermore, there is substantial evidence that SHS has adverse cardiovascular consequences as early as the first decade of life, including when the fetus is exposed to maternal smoking or maternal SHS in utero and in children who have no other atherosclerosis-promoting risk factors. 22–24

Children of smoking parents are significantly more likely to be exposed to SHS 25 and are more likely to smoke tobacco later in life. This may be associated with many interrelated factors, including SHS exposure itself, 3,26,27 parental modeling, 28,29 or physical sensitivities to SHS. 30 However, recent studies suggest that SHS in childhood is an independent factor in susceptibility to smoking initiation, 31 that home smoking bans may delay or prevent smoking initiation among children of smokers, 32 and conversely that SHS exposure may be a mediating factor making adolescent quitting less likely within the context of a smoking family. 25 Thus, childhood SHS exposure may also have indirect impacts on lifetime cardiovascular health by increasing the likelihood that SHS-exposed children will choose to smoke in adolescence and adulthood.

In the past 2 decades since the last publication of an American Heart Association statement concerning the health of children exposed to SHS, 33 there has been substantial evolution of epidemiological and clinical research related to SHS. This statement updates previous statements with recent data concerning SHS and cardiovascular disease (CVD) risk in children. This document emphasizes the adverse effects of SHS on cardiovascular health in children and includes discussions on mechanisms of vascular disruption and platelet activation, oxidation and inflammation as noted in animal studies, human endothelial dysfunction, increased vascular stiffness, autonomic dysfunction, and changes in vascular structure. The effectiveness and limitations of currently available behavior modification techniques and smoking bans to reduce SHS exposure in children are also addressed. The purpose of this statement is to increase awareness among providers and policy makers of the substantial SHS exposure that continues to be prevalent in children and its lifetime, adverse cardiovascular consequence.

**Epidemiology of SHS Exposure**

**Prevalence of SHS Exposure in Children**

Approximately 24 million nonsmoking children and adolescents in the United States are currently exposed to SHS. 3 Nationally representative data from 2011 to 2012 NHANES (National Health and Nutrition Examination Survey) show that nearly 41% of children 3 to 11 years of age and 34% of adolescents 12 to 19 years of age had detectable serum cotinine levels (>0.05 ng/mL), which
is consistent with exposure to SHS.\textsuperscript{3} Cotinine, a metabolite of nicotine found in biological fluids, is a commonly used marker of tobacco smoke exposure.\textsuperscript{34} These SHS exposure estimates represent a substantial reduction in prevalence since the NHANES III survey from 1988 to 1994\textsuperscript{35} (Figure 1). The majority of this decline in SHS exposure in children appears to have occurred by the early 2000s,\textsuperscript{35,37,38} with a relative leveling off in the past decade.\textsuperscript{37} However, a national sample of nonsmoking middle school– and high school–aged adolescents who self-reported exposure to SHS revealed declines in SHS from 59\% to 34\% between 2000 and 2009.\textsuperscript{39} Despite these significant declines in children and adolescents exposed to SHS over the past 30 years, the prevalence remains strikingly high, with \(\approx 1\) in 3 children in the United States still exposed to SHS.

These declining trends in SHS exposure among children, however, are not consistent worldwide. A recent study of SHS exposure in rural areas of China identified that 68\% of children were exposed to SHS at home and that exposure prevalence was amplified in households with low income or low educational status of the head of household.\textsuperscript{40} The prevalence of adult SHS exposure is \(\approx 35\%\) in Shanghai but was surprisingly higher in households with children <18 years of age.\textsuperscript{41} A 43-country report of the World Health Organization’s Global Youth Tobacco Survey of children 13 to 15 years of age was released in 2002.\textsuperscript{42} Home SHS exposure in this age group exceeded 70\% in 6 sites in India, was 69\% in Indonesia, and was a median of 49\% across all surveys.\textsuperscript{42} Updated nationwide representative data from India in 2009 were lower at 22\%, but data remained high in Indonesia in 2014 (57\%).\textsuperscript{43,44} Although public smoke-free

bans were instituted in 2007 in Hong Kong and in 2011 in China, evidence from Hong Kong indicates that smoking bans have displaced smoking from public to private spaces, including the home, increasing home SHS exposure in children.\textsuperscript{45} Thus, childhood exposure to SHS both at home and in public places remains significant in many countries worldwide, particularly in South Asia and East Asia. Results from a recent systematic review of SHS exposure and CVD reaffirm these findings, confirming a high prevalence of SHS exposure in both low- and middle-income countries.\textsuperscript{46}

Smoking Inside the Home

It has long been recognized that parental smoking is a major source of SHS exposure for nonsmoking children and adolescents.\textsuperscript{17} Children have less control over home and social environments, leading to an increased likelihood of involuntary, confined exposure to SHS. These developmental barriers, combined with physiological differences from adults discussed later,\textsuperscript{47} reflect that nonsmoking children have significantly higher measurable exposure to SHS than nonsmoking adults.\textsuperscript{38}

The proportion of children 3 to 11 years of age living with someone who smokes inside the home declined from 38\% in 1994 to 1998 to 24\% in 1999 to 2004\textsuperscript{35} to 18\% in 2007 to 2008,\textsuperscript{36} with similar declines seen among nonsmoking adolescents (35\%, 20\%, and 17\%, respectively). This is consistent with the secular decline in overall adult smoking prevalence, as well as an increase in voluntary smoke-free home rules.\textsuperscript{48} These reductions in smoking inside the home contribute substantially to the overall decline in childhood SHS exposure. However, youth who remain in smoking home environments still face near-certain SHS exposure.

Epidemiological studies report that >98\% of children and adolescents living with someone who smokes at home have detectable SHS exposure,\textsuperscript{36} a proportion that has not appreciably declined since 1988.\textsuperscript{49} However, when the data of at-home SHS exposure\textsuperscript{35,36,49} are combined with data on overall prevalence of SHS exposure among children,\textsuperscript{35,36} we estimate that only 1 in 3 SHS-exposed youth has exposure within the home environment (Figure 2A and 2B), suggesting that the majority of children and adolescents with detectable SHS exposure are exposed outside their home or in an automobile. This is consistent with a study of inner-city youth in which 95\% reported SHS exposure outside the home, often in relatives’ or friends’ homes or in cars.\textsuperscript{50} Although both in-home and in-car smoking bans are associated with less SHS exposure in children,\textsuperscript{51} 71\% of smoking parents did not report having a smoke-free car policy, and only a third of parents who enforced a strict in-home smoking ban also enforced a smoking ban in the car.\textsuperscript{52} This is especially important because SHS in a car can be significant, even with the windows open.\textsuperscript{53,54}

![Figure 1. Trends in secondhand smoke (SHS) exposure among US nonsmoking children and adolescents.](http://circ.ahajournals.org/)

Data were compiled from NHANES (National Health and Nutrition Examination Survey) periodic survey data.\textsuperscript{3,35,36} Solid line indicates children 3 to 11 years of age; and dashed line, adolescents 12 to 19 years of age.
SHS Exposure Trends, Demographics, and Socioeconomics

Although there has been a reduction in overall SHS exposure, racial disparities persist. There is some indication that the metabolism of toxins derived from SHS differs by race. For a given amount of exposure, cotinine levels may be higher in blacks. NHANES data suggest that 31 million non-Hispanic white non-smokers were exposed to SHS in 2011 to 2012, including 7 million children. Additionally, 12 million non-Hispanic black non-smokers were exposed to SHS, including 3 million children, and 6 million Hispanic non-smokers were exposed to SHS, including 2 million children, during the same time period. Specifically, the prevalence of SHS exposure declined comparably from 1999 to 2000 to 2011 to 2012 among non-Hispanic white children (−41%) and Hispanic children (−39%). The decline observed among non-Hispanic black children, however, was substantially less (−20%; Figure 3). During 2011 to 2012, SHS exposure in 3- to 11-year-old children was significantly higher among non-Hispanic blacks (68%) than non-Hispanic whites (37%) and Hispanics (30%; P < 0.05). Prevalence of SHS exposure in adolescents 12 to 19 years of age was also significantly higher among non-Hispanic blacks (55%) than non-Hispanic whites (36%) and Hispanics (17%; Figure 4). Thus, although cotinine metabolism differs by race, higher cotinine levels in blacks also may be attributable to increased exposure to SHS.

In addition to differences in SHS exposure by race/ethnicity, there are significant differences by SES. NHANES data from 2011 to 2012 indicate that individuals living below the poverty level have greater exposure to SHS (43%) than those living above the poverty level (21%). By education, SHS exposure was highest among individuals with grade 11 or less education (28%) and lowest among those with a college or graduate diploma (12%). Exposure to SHS was higher among individuals who rented their housing (37%) than individuals who owned housing (19%). Importantly, the prevalence of voluntary home smoking bans was significantly lower for households with low income, a single parent, or lower educational attainment. Many individuals with low SES live in multiunit housing where SHS can infiltrate smoke-free units and areas shared by others who smoke. Recent estimates indicate that 80 million individuals in the United States live in multiunit housing, and ≈25% of these individuals are below the poverty level. The living environment is recognized as a setting where substantial exposure to SHS occurs for children and youth. There is scientific evidence to support efforts designed to prohibit smoking in commonly shared areas in subsidized housing.

A recent systematic review generated from 41 studies across 21 countries adds to the NHANES findings indicated by...
ing that parental smoking, low SES, and lower education are frequently and consistently associated with SHS exposure in children and youth.\textsuperscript{59} The significance of sociodemographic factors is also supported by data from Denmark,\textsuperscript{60} the United Kingdom,\textsuperscript{61} and Australia.\textsuperscript{62} More recently, longitudinal studies have focused on the effects of in utero SHS exposure on developmental and health outcomes in childhood, adolescence, and young adulthood,\textsuperscript{63-65} showing that these adversities also are disproportionately prevalent in minorities and lower-SES groups. Taken together, these findings continue to underscore the importance of sociodemographic factors, including household SES, educational levels of parents/guardians, and the home environment, in increasing the likelihood of childhood SHS exposure.

**Influence of SHS Exposure on Childhood Obesity, Dyslipidemia, and the Metabolic Syndrome**

An area of emphasis has been the deleterious effect of in utero SHS exposure on body weight status. The overall pattern appears to be one of lower weight at birth and larger postnatal weight gain, which is recognized to predict future obesity. Supporting this, data show that in utero exposure to tobacco smoke has obesogenic effects.\textsuperscript{66} Results from the longitudinal Healthy Start Study suggest that in utero exposure to SHS is associated with intrauterine growth retardation and rapid postnatal compensatory growth.\textsuperscript{63} Specifically, at birth, those exposed to in utero SHS had reduced fat mass ($P=0.007$) and fat-free mass ($P=0.02$). However, at 5 months of age, exposed and unexposed offspring were phenotypically similar in overall weight, length, and body composition. After adjustment for birth weight, offspring exposed to in utero SHS had greater fat mass ($P=0.04$) and fat-free mass ($P=0.04$), suggesting postnatal compensatory growth.\textsuperscript{63}

The National Institute of Child Health and Human Development Study, a longitudinal study that followed up a cohort of children from birth, examined the long-term effect of either in utero SHS resulting from maternal smoking or exposure of the nonsmoking pregnant mother to SHS from a partner or other household member on obesity among offspring at adolescence, independent-
ly of birth weight.\textsuperscript{55} After adjustment for maternal and child factors, the odds of adolescent obesity increased with both in utero SHS exposure (odds ratio, 1.57; 95% confidence interval [CI], 1.03–2.39) and exposure of the pregnant mother to SHS (odds ratio, 1.53; 95% CI, 1.04–2.27). Furthermore, the odds for obesity in adolescence increased 2-fold among adolescents exposed to any in utero SHS (odds ratio, 2.10; 95% CI, 1.24–3.56) compared with those without in utero SHS exposure.\textsuperscript{56}

The Southern California Children’s Health Study collected data on current SHS exposure and maternal smoking during pregnancy on 3318 children who were \( \approx \)10 years of age at study entry. Both in utero SHS exposure and current SHS exposure were associated with greater subsequent body mass index over an 8-year period spanning from adolescence through young adulthood.\textsuperscript{57} Maternal smoking during pregnancy has been reported to result in a 60% greater chance of the child being overweight at 4 years of age.\textsuperscript{68} A Swedish cohort study of 5- to 15-year-old children has suggested that parental smoking is associated with a 3% to 4% body mass index increase in children compared with control subjects.\textsuperscript{69} In a large study of German children, SHS exposure after birth was significantly associated with overweight status at 6 years of age.\textsuperscript{64} The mechanisms behind this association are not well understood. Taken together, results of these studies suggest adverse effects of SHS exposure, including in utero exposure on body mass index, in children.

Although the findings are not consistent, some studies suggest that SHS exposure may have an adverse effect on lipid metabolism. In utero SHS exposure was associated with lower high-density lipoprotein cholesterol levels in children, even after adjustment for postnatal SHS exposure.\textsuperscript{70,71} Another study noted that apolipoprotein B was lower in SHS-exposed teenagers compared with control subjects.\textsuperscript{72} Furthermore, an ex vivo study performed in healthy nonsmokers exposed to SHS for 5.5 hours suggested that exposure led to lipid peroxidation, low-density lipoprotein cholesterol (LDL-C) modification, and accumulation of LDL-C in macrophages.\textsuperscript{73} Research findings on the effect of SHS exposure on blood pressure show more inconsistencies and are less well studied, although an increase in blood pressure in those exposed to SHS has been reported.\textsuperscript{22} SHS exposure is clustered with other atherosclerosis-promoting risk factors and the metabolic syndrome in adolescents.\textsuperscript{74}

\section*{Summary}

Epidemiology of childhood SHS exposure:
- Up to 4 of 10 children have detectable cotinine.
- Parental smoking is a major source of SHS exposure in childhood.
- Nearly all children living with someone who smokes is exposed to SHS.
- SHS exposure is highest in black youth in the United States.
- SHS exposure is inversely linked to SES and educational status.
- In utero/postnatal SHS exposure is associated with obesity and cardiovascular risk factors.

\section*{ECONOMIC IMPACT OF SHS EXPOSURE}

Tobacco smoke (from both smoking and SHS exposure) has a significant economic impact on direct healthcare costs and loss in productivity. Annual tobacco smoking-related economic costs in the United States exceed \$289\ billion, and exposure to SHS caused an estimated \$5.6 billion yearly in lost productivity over the 3-year period between 2009 and 2012.\textsuperscript{14} Among children, living with at least 1 smoker is associated with a modest increase in emergency department expenditures\textsuperscript{75} and inpatient use.\textsuperscript{76} Some estimate that the additional cost associated with birth complications in pregnant women smoking tobacco or being exposed to SHS may be as high as \$2 billion per year.\textsuperscript{77} Lightwood et al\textsuperscript{78} reported the health and economic benefits of smoking cessation during pregnancy, estimating savings of \$572 million in direct pediatric medical expenses in 7 years.

SHS exposure has a negative economic impact on the education system. Children exposed to SHS have higher rates of adverse behavioral and cognitive effects, including attention-deficit/hyperactivity disorder.\textsuperscript{79} Max et al\textsuperscript{79} estimated that the costs to the education system from SHS may be 4 times higher than the annual healthcare cost attributable to attention-deficit/hyperactivity. Using school absenteeism as a surrogate measure of child health,\textsuperscript{80–82} Levy et al\textsuperscript{83} showed in a nationally representative sample of 6- to 11-year-olds that children living with adults who smoke at home are absent from school 1.5 more days a year than children living with nonsmokers. Caregivers’ time tending to children absent from school is estimated to cost \$227 million each year. The authors concluded that household SHS exposure is significantly associated with school absenteeism.\textsuperscript{83}

Although there are no data quantifying the economic impact of SHS exposure–induced cardiovascular consequences in children, the above data support the global adverse economic impact of SHS exposure in childhood.

\section*{Economics of Tobacco Cessation Programs/Efforts}

The best way to reduce SHS exposure in children is to eliminate the source of the exposure. Thus, tobacco cessation programs for adults are an effective modality for decreasing the prevalence of SHS exposure. Resources spent on education, counseling, and health promotion are highly efficient, resulting in substantial healthcare cost savings and public health improvements. In 2015, an estimated \$25
billion in revenue from tobacco settlements and taxes was collected by all 50 states, with <2% of the revenue being spent on programs that help prevent children from smoking and help smokers quit. These prevention programs are known to reduce smoking, to save lives, and to reduce tobacco-related healthcare costs that are estimated to run into hundreds of billions of dollars annually.

Data from Washington State (2000–2009) indicated that tobacco cessation programs are not just a cost-effective intervention but actually have a savings multiplier effect, saving in excess of $5 for every dollar spent. Over the 10-year period, this program prevented almost 36,000 hospitalizations, a savings of $1.5 billion compared with $260 million spent on the program. A 2013 study conducted in California, a leader in tobacco prevention, found that from 1989 to 2008, the state’s tobacco control programs reduced healthcare costs by $134 billion compared with $2.4 billion spent administering the programs.

The economic impact of changing smoking locations is also substantial. For example, prohibiting smoking in all US subsidized and public housing is estimated to generate annual cost savings of ≈$500 million. These figures are likely an underestimate because proper accounting of life-course benefits cannot be modeled with currently available data. Thus, although the economic costs of smoking tobacco and SHS exposure are significant, well-designed and well-targeted programs can minimize these costs, at great benefit to society. Whereas studies have not quantified the economic consequences of the cardiovascular effects of childhood SHS, we speculate that this is substantial in view of its persisting and lifetime impact.

Summary
Childhood SHS exposure is associated with
- Higher emergency room visits, inpatient use, and medical expenses
- Negative impact on the education system
- Higher rates of behavioral and cognitive adversities
- Increased school absenteeism

CARDIOVASCULAR DYSFUNCTION ASSOCIATED WITH SHS EXPOSURE IN CHILDREN

Chemical Composition of SHS and Biochemical/Mechanistic Effects

The multiple gases and chemicals of SHS make the causal attribution to any single component challenging. Effects of tobacco smoke depend on whether the exposure is from direct smoking or SHS, the distance of those exposed from source, the length of time from the constituents entering the environment to the individual being exposed (environmental SHS aging), and whether the SHS is mainstream or side-stream smoke. Mainstream smoke is the inhaled component, some of which is then exhaled, whereas side-stream smoke (amounting to 75% of the smoke generated by a cigarette) emanates directly from the burning end of the cigarette (Figure 5). Thus, mitigation of CVD risk from SHS depends critically on the chemicals present in side-stream smoke. The precise composition of SHS depends on fluctuating conditions, including pH, ambient temperature, atmospheric gas composition, and degree of combustion. For example, some constituents such as carbon monoxide and nicotine dissipate quickly, whereas certain organic chemicals persist over time. In addition, biochemical changes in these toxins over time may affect the composition of SHS. This complex milieu synergistically results in the adverse consequences of SHS. Although interested stakeholders make much ado

Figure 5. Mainstream and side-stream smoke.
about filtered versus unfiltered distinctions or low-tar varieties, emitted chemical compositions of side-stream smoke may differ little among them. Specific chemical constituents present in SHS number in the thousands; a few of the most prominent chemicals are presented in the Table. Side-stream smoke, containing \( \approx 3 \) times more toxins than mainstream smoke, can be as dangerous as or potentially more dangerous than directly smoking, depending on intensity and length of exposure.\(^97,98\) Some studies suggest that the toxicity of some constituents in side-stream smoke actually increases over time as a result of ambient environmental reactions in which certain compounds deposit onto surfaces, resulting in continuing exposure, and highly volatile gas constituents remain suspended in air.\(^94,96-100\) These compound-specific features further obscure the mechanisms of action because the degree of the exposure may vary on the basis of the type of compound in question.\(^97,101\) Although many noxious chemicals are associated with SHS exposure, the precise degree of exposure varies from constituent to constituent, and CVD-relevant effects may vary accordingly. Regardless of mechanism, consensus has developed about quantifying the severity of tobacco smoke exposure by measuring nicotine and its metabolites or particulate matter.\(^16,34,89,102\)

### Mechanisms of Vascular Disruption

Cigarette smoke, both mainstream and side stream, is understood from in vitro, in vivo, and epidemiological studies to have acute and subacute effects leading to cardiovascular consequences. The specific mechanistic domains include short-term effects on endothelial function, platelet function, vasoconstriction, autonomic function, heart rhythm, and inflammation.\(^16,89\) Subacute effects can include inflammation via oxidative stress, endothelial dysfunction, dyslipidemia, thrombosis, and reduced insulin sensitivity.\(^16,89\) Although the sheer number of compounds precludes a full account of the mechanism of each compound here, a few examples deserve mention. Nicotine is associated with hemodynamic alterations, dyslipidemia, and insulin resistance.\(^103-105\)

Acrolein, a volatile organic chemical, is highly reactive, causes oxidative stress and inflammation, and is linked to hypertension, dyslipidemia, arrhythmia, and thrombosis. Crotonaldehyde is an atherogenic compound that induces plaque instability, increases thrombosis, and may have negative inotropic effects.\(^106-108\) Cadmium can cause inflammation and facilitate atherosclerosis.\(^109,110\)

Lead exposure may cause hypertension.\(^111,112\) Various particulate matters are known to be arrhythmogenic and to precipitate CVD events.\(^113-115\)

It is to be noted that exposure to carbon monoxide and metals is minimal through SHS.\(^16\) Nicotine exposures are also quite low, in part because nicotine dissipates rapidly from SHS.\(^16\) Conversely, acrolein and other organic chemicals persist in SHS over time, are highly reactive, and are known to produce oxidative stress, inflammation, and endothelial dysfunction and to promote blood clotting.\(^16\) Moreover, other substances can adhere to the smoking-elaborated particulate matter and enhance their toxicities.\(^100\)

With respect to children, investigators have demonstrated that SHS exposure markers are elevated in a graded fashion in concert with higher SHS exposure. Cotinine levels are detectable in fetal and cord blood serum and appear to be higher in younger children (compared with adults) as a result of either higher exposure from faster respiratory rates or inadequate cotinine metabolism.\(^47,116-119\) After adjustment for degree of exposure, black children appear to have higher levels of SHS markers compared with non-Hispanic and Hispanic children, underscoring race/ethnicity and metabolic differences.\(^49\) In summary, SHS is an intricately interactive vector for producing cardiovascular consequences.

### Table. Selected Chemicals Present in SHS and Their Relative Strength in Side-Stream Compared With Mainstream Smoke

<table>
<thead>
<tr>
<th>SHS Chemicals</th>
<th>Enrichment Ratio, Side-Stream vs Mainstream Smoke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>8–11</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>2.5–4.7</td>
</tr>
<tr>
<td>Nicotine</td>
<td>2.6–3.3</td>
</tr>
<tr>
<td>Carbonyls</td>
<td></td>
</tr>
<tr>
<td>Acrolein</td>
<td>8–15</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.1–50</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>5.6–8.3</td>
</tr>
<tr>
<td>Benzene</td>
<td>5–10</td>
</tr>
<tr>
<td>Pyridine</td>
<td>6.5–20</td>
</tr>
<tr>
<td>Ammonia</td>
<td>40–170</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>4–10</td>
</tr>
<tr>
<td>Hydrogen cyanide</td>
<td>0.1–0.25</td>
</tr>
<tr>
<td>Particulates: tar</td>
<td></td>
</tr>
<tr>
<td>Polyaromatic hydrocarbons</td>
<td>1.3–1.9</td>
</tr>
<tr>
<td>Nitrosamines</td>
<td>0.6–100</td>
</tr>
<tr>
<td>Polonium</td>
<td>1–4</td>
</tr>
<tr>
<td>Nickel</td>
<td>13–30</td>
</tr>
<tr>
<td>Cadmium</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Summary
The effects of SHS exposure are dependent on
- Length of time exposed
- Intensity of exposure
- Aging of the SHS constituents in the environment
- Race and age

Cardiovascular effects of key components of cigarettes include
- Nicotine: hemodynamic alterations
- Acrolein: oxidation, inflammation, atherogenesis, hypertension, and arrhythmia
- Crotonaldehyde: plaque instability and thrombosis
- Cadmium: inflammation
- Lead: hypertension
- Particulate matter: arrhythmias and inflammation

Animal Studies Linking SHS Exposure to Mechanisms of Atherosclerosis
Although the specific mechanisms of SHS exposure on cardiovascular health in humans are not well understood, animal studies have helped to shed light on potential mechanistic effects. Experimental animals are different from humans in many respects (lipoprotein profiles, blood pressures, patterns of breathing [eg, nose versus mouth], and other biological dissimilarities); however, there is a consistent body of evidence from a variety of animal species on the potential atherogenic effects of SHS. Most of the early work was done with SHS exposure in adult animals exposed to high doses of SHS, but recent studies have examined environmentally plausible levels of SHS and their effects on vascular biology and atherosclerosis lesion development. It should be noted, however, that most such studies do not provide a biochemical assessment of postexposure levels. Although the respiratory properties of animals are different from those of humans, animal studies are especially important in studying the life-course effects of SHS exposure because of their shorter lifespan. Thus, animal studies have given sophisticated mechanistic insights into the possible pathogenesis of SHS exposure–related vascular disease.

Mouse Studies
In 2001, Gairola et al120 found that side-stream cigarette smoke accelerates atherogenesis in apolipoprotein E knockout mice. When these mice were maintained on a Western diet and exposed to relatively high dose of SHS, there was a duration-dependent increase in atherosclerosis lesion development. In 2004, Tani et al121 documented increased carotid artery intima-media thickness (CIMT) in mice exposed to SHS compared with controls. This was associated with an excessive antibody response to oxidized LDL-C, raising the possibility that SHS and high lipoprotein levels might have an additive proatherogenic effect. Because human studies have linked SHS exposure to accelerated lipid peroxidation and LDL-C modification, this additive effect could be relevant to children and young adults.73 The mechanism of these effects has also been studied in mice. Zhang et al122 documented high levels of proinflammatory cytokines such as interleukin-6 in adult mice exposed to SHS. Knight-Lozano et al123 studied the effect of SHS on normal and dyslipidemic mice and documented high levels of oxidative stress and increased mitochondrial DNA damage of aortic tissue in SHS-exposed mice; this effect was maximal in mice with both dyslipidemia and SHS exposure.

Fetterman et al124 examined the effects of in utero and neonatal SHS exposure on both atherosclerosis lesion development in later life and oxidative stress and mitochondrial DNA damage in aortic tissue. Mice were exposed to 1 mg/m3 SHS (4–5 ppm carbon monoxide, 200–300 µg/m3 nicotine), a level frequently found in smoky entertainment areas for adults. Both in utero and early-life exposure significantly increased adult atherosclerosis lesion development and resulted in notable alterations in the aortic tissue, mitochondria, and their genomes. Oxidative stress levels were also markedly increased in the SHS-exposed animals.

Rat Studies
Mullick et al125 used quantitative fluorescent microscopy to study endothelial cell injury after SHS exposure. In rats, SHS exposure increased carotid artery LDL-C accumulation >4-fold compared with filtered air exposure and was associated with marked ultrastructural damage to the carotid artery endothelial cells. Biochemical studies implicated a potentially damaging role from highly reactive carbonyl components.125

Hutchison et al126 examined the effects of SHS on vascular reactivity in newborn rats. In utero or neonatal exposure to SHS resulted in enhanced vasoconstriction, reduced endothelium-dependent dilatation, and decreased sensitivity to nitroglycerin, suggesting that exposure to SHS might have detrimental effects on vascular endothelial and smooth muscle function. Mechanistic studies in rats have also linked SHS exposure to increased LDL-C accumulation in ex vivo perfused arteries.127

Rabbit Studies
Zhu et al128 exposed cholesterol-fed rabbits to SHS, finding an SHS dose–dependent increase in percent aortic involvement with atherosclerosis-like lesions. An increase in bleeding time was also seen, suggesting an acquired platelet dysfunction. Hutchison et al129 examined the effects of a high-cholesterol diet with or without SHS exposure in rabbits, finding both endothelial dysfunction and increased atherogenesis, with greater impairment of endothelial function in the combined high-cholesterol and SHS-exposed animals compared with those with high cholesterol only.
Cockerel Studies

In 1993, Penn and Snyder130 exposed 6-week-old cockerels to side-stream smoke or filtered air, finding markedly increased atherosclerotic plaque in the abdominal aorta. In a subsequent study, Penn et al131 then decreased the exposure of SHS to a level often observed in a smoky bars and again found enhanced atherosclerosis in the cockerels exposed to even this lower dose of SHS.

Taken together, the data from these animal studies suggest that exposure to environmentally plausible levels of SHS in early life (including in utero) can increase atherosclerosis lesions later in life. Inferred mechanisms include increased oxidative stress, proinflammatory effects, mitochondrial damage, and impaired endothelial function.

Human Studies: Changes in Vascular Endothelial Function

The vascular endothelium plays a central role in cardiovascular homeostasis, making or modifying a large number of chemicals that regulate arterial tone, thrombogenesis, cell proliferation, leukocyte adhesion, and platelet interaction, among others. A healthy endothelium maintains a normal dilator state and antithrombotic surface, whereas endothelial dysfunction predisposes to vasoconstriction, thrombosis, cell proliferation, and leukocyte adhesion. These processes are thought to play a key role in early atherogenesis. Normal endothelial function and the consequences of endothelial dysfunction have been summarized in detail elsewhere.132,133 Endothelial dysfunction has been associated with a variety of cardiovascular risk factors134 and predicts future cardiovascular events.

One method for assessing endothelial function in humans noninvasively is the measurement of arterial flow-mediated dilatation (FMD) by ultrasound. This vasodilator response to shear stress is attributable to the endothelial release of nitric oxide, a chemical entity responsible for vasodilatation, inhibition of leukocyte adhesion, platelet aggregation, and smooth muscle cell proliferation. The measurement of FMD was first described in 1992 in children and young adults at risk of atherosclerosis135 and has been shown to predict cardiovascular events.136

Acute Arterial Endothelial Dysfunction With SHS Exposure

Although the evidence on acute arterial endothelial dysfunction in children and adolescents is limited, adult studies suggest potential mechanistic changes. In 2001, Otsuka et al137 examined the acute effects of SHS on the coronary circulation in healthy young adults. The authors measured coronary flow velocity reserve in response to adenosine in young adult male nonsmokers compared with smokers (mean age, 27 years) before and after a 30-minute exposure to environmental tobacco smoke. They found that coronary flow velocity reserve was significantly impaired by exposure to SHS in both the nonsmokers and smokers. This acute effect of SHS on coronary physiology has also been examined in women. Sumida et al138 examined the effects of SHS on endothelium-dependent coronary artery dilatation in 38 women 40 to 60 years of age, finding that acetylcholine caused coronary constriction in passive and active smokers and led to a normal dilator response in nonsmokers.

At a mechanistic level, the effects of cigarette smoke on endothelial function ex vivo have been examined in a number of studies. Cigarette smoke increases adhesion molecule expression on human endothelial cells139 and increases human monocyte adhesion to endothelial cells, an effect reversible by the nitric oxide precursor l-arginine.140 Cigarette smokers have also been shown to have increased tissue factor expression in atherosclerotic plaques.141

Hausberg et al142 studied the effect of short-term SHS exposure on muscle sympathetic nerve activity in 17 healthy young nonsmokers (age, 28±6 years). One smoke inhalation session increased resting muscle sympathetic nerve activity by ≥20% in the SHS-exposed group but not in the control group. This finding could in part underscore the association between SHS exposure and blood pressure in children.143

Effects of Long-Term SHS Exposure on Arterial Endothelial Function

In 1996, Celermajer et al8 studied 78 healthy teenagers and young adults (age, 15–30 years): 26 active smokers, 26 who had never smoked but had been exposed to SHS for at least 1 hour daily for ≥3 years, and 26 control subjects who were not SHS exposed or actively smoking. Arterial FMD showed profound impairment in the passive and active smoking young adults. Arterial dilatation induced by nitroglycerin was similar in all groups, localizing the defect in vascular reactivity to the endothelium.

This finding was later confirmed by Kallio et al9 in younger children. As part of a longitudinal study in Finland, children had annual serum cotinine concentrations measured between 8 and 11 years of age to assess SHS exposure and had FMD assessed at age 11 years. Exposure to SHS as measured by cotinine was associated with impaired endothelial function in a dose-dependent manner in preteenage children (Figure 6). Yang et al143 studied FMD in 16-year-old Tibetan school students and documented impaired endothelial function in those exposed to SHS.

Juonala et al143 examined the effects of parental smoking in childhood on endothelial function in young adults 19 to 27 years after the period of SHS exposure in the home. Two populations were studied, 1 from Finland and 1 from Australia, and both groups saw reduced FMD in participants whose parents had smoked compared with those whose parents had not smoked. These findings suggested that SHS exposure in childhood could cause...
impairment in endothelial function, observable many years later. However, the authors noted that arterial endothelial dysfunction related to passive smoking might be at least partially reversible in healthy young adults. This reversibility was documented by Raitakari et al., who examined endothelium-dependent dilatation in those formerly exposed to SHS compared with those currently exposed to SHS who were 15 to 39 years of age. FMD was 2% in those currently exposed, 5% in those formerly exposed, and 9% in control subjects, suggesting partial reversibility of SHS-related endothelial dysfunction in those who were removed from SHS-containing environments.

In summary, there is compelling evidence that exposure to SHS in children and young adults is associated with arterial endothelial dysfunction, a likely predisposing factor to atherosclerosis and increased CVD risk in later life.

**Mechanisms**

A number of potential cellular mechanisms related to endothelial dysfunction have been documented in association with SHS. Studies have documented markers of oxidative stress in SHS-exposed and nonsmoking, non–SHS-exposed groups, including increased levels of glutathione peroxidase and catalase in those exposed to SHS. Inflammatory markers such as C-reactive protein and oxidized LDL-C are also higher in those who are SHS exposed. The presence of such reactive oxygen species and inflammatory markers is known to reduce the production and activity of endothelial nitric oxide synthase. Following up on animal work implicating mitochondrial damage as a potential pathogenetic mechanism in SHS exposure, a recent review by Yang et al. of fetal, childhood, and adult exposure to SHS and mitochondrial damage and dysfunction concluded a potentially important role of mitochondrial abnormalities in mediating CVD susceptibility.

**Changes in Vascular Tone/Stiffness and Structural Vascular Changes**

Adequate arterial function includes the transmission of blood flow to downstream tissue capillary beds with minimal energy loss and regulation of blood flow in those tissue beds and flow proportional to metabolic demand. These are determined by the structure and function of large conduit and small resistance arteries. Assessment of arterial structure includes, but is not limited to, measurement of CIMT and arterial stiffness. SHS exposure appears to distort arterial structure. These distortions are of clinical relevance; recent reports indicate that peripheral artery disease is higher in adults who smoked cigarettes during childhood even after adjustment for other predictors of peripheral artery disease.

CIMT is assessed by ultrasound imaging of the common carotid artery near the bifurcation into external and internal carotid arteries. CIMT captures the effect of accumulated cardiovascular risk factors to the arterial wall. With every 1-mm increase in CIMT measurement in adults, the hazard ratio for CVD increases by 2.5. CIMT also measures localized plaque formation, which may have independent prognostic information. The Atherosclerosis Risk in Communities study demonstrated in adults a clear association between SHS exposure and CIMT thickening. Other studies suggest that SHS exposure increases CIMT in younger adults and in those with low levels of other CVD risk factors. In children with in utero SHS exposure, CIMT was thicker, whereas postnatal SHS exposure appeared to be less predictive of a thicker CIMT. Some studies suggest a dose-dependent relationship between postnatal SHS exposure (Figure 7) and thicker CIMT, but other investigators did not find this relationship. In summary, although increased CIMT as a result of childhood SHS exposure is not conclusive of CVD, a relationship that will take decades to observe, this is compelling medium-term proxy evidence that indicates deleterious effects of SHS on the vasculature.

Arterial stiffness, a measure of the material properties of the artery, is associated with traditional CVD risk factors and predicts future CVD and hypertension. Several methods can be used to measure arterial stiffness, including carotid-femoral pulse-wave velocity, the degree of pulse-wave reflection called augmentation index, or arterial distensibility, which is a change in diameter of the artery from diastole to systole. In adults, long-term SHS exposure decreased carotid artery distensibility, including in the obese, the elderly, and those...
A recent longitudinal study by Dixit and colleagues measured the effects of SHS exposure in utero and during childhood on arrhythmia development as an adult. SHS exposure in utero and during childhood was associated with atrial fibrillation later in life. SHS exposure in early life may be an important, potentially modifiable risk factor for the development of late arrhythmia.

The cardiac effects of direct smoking and SHS exposure in adults are well documented and could suggest hypotheses for studying children exposed to SHS. Cigarette smoking is associated with the release of epinephrine and norepinephrine. Thus, cigarette smoking has a powerful sympathetic excitatory effect influencing sympathetic drive to blood vessels, skin, and the heart. Supporting these theoretical concerns, long-term adult smokers have a blunted heart rate response to exercise and decreased exercise tolerance compared with nonsmokers, caused in part by downregulation of cardiac β-adrenergic receptors. SHS exposure generates an autonomic system imbalance associated with increased cardiac vulnerability and may lead to arrhythmias such as atrial fibrillation, ventricular tachycardia, and ventricular fibrillation, especially in those with other pre-existing CVD risks.

The pathophysiological mechanism of smoking-related arrhythmia is complex and influenced by several of the major components of tobacco smoke. It includes alteration in autonomic function and a profibrotic effect of nicotine and carbon monoxide on myocardial tissue with consequent increased sensitivity to catecholamine. As noted above, specific components of SHS such as carbon monoxide may contribute to the generation of ventricular arrhythmias. Nicotine, carbon monoxide, and oxidative stress can induce fibrosis at different cardiac sites, resulting in a structural remodeling that can predispose the patient to arrhythmias. These cardiac effects, however, are likely negligible in those exposed to SHS because levels of nicotine and carbon monoxide are relatively low.

### Autonomic Dysfunction and SHS Exposure

In utero or postnatal SHS exposure increases the risk of SIDS. Compared with infants who were not exposed to SHS either in utero or postnatally, the risk of SIDS is greater in infants exposed both in utero and in the postnatal period (3-fold increase) and in those with only postnatal exposure (2-fold increase). Furthermore, the risk of SIDS increases with increasing dose of SHS exposure. In the Wales Perinatal Survey, more than half of the infants known to have died suddenly lived in households with SHS. Behm et al studied the association between a higher prevalence of smoke-free homes and decreasing rates of SIDS, controlling for an important risk factor for SIDS, supine sleep position. On a population basis, for every 1% absolute increase in the prevalence of smoke-free homes, SIDS rates decreased 0.4%.

### Arrhythmia and SHS Exposure

Acute cardiovascular effects of SHS in the young include tachycardia and an increase in blood pressure. An important potential pathway for tobacco exposure in children is in utero. Interestingly, the effects of in utero and postnatal SHS exposure on autonomic function seem to be sex specific. Schuetz and Eiden examined the association between in utero SHS exposure and neonatal heart rate and heart rate variability assessed at 2 to 4 weeks of age. Neonates with in utero SHS exposure had higher heart rates and lower heart rate variation with breathing than those in the nonexposed group. For unexplained reasons, boys who were exposed to SHS either in utero or in the postnatal period had higher heart rates and lower heart rate variation than SHS-exposed girls.

A recent longitudinal study by Dixit and colleagues measured the effects of SHS exposure in utero and during childhood on arrhythmia development as an adult. SHS exposure in utero and during childhood was associated with atrial fibrillation later in life. SHS exposure in early life may be an important, potentially modifiable risk factor for the development of late arrhythmia.

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The mechanism behind SHS exposure and SIDS may include effects on the normal regulation of breathing. Experimental data from animal studies have shown that exposure to SHS can have adverse effects on brain cell development.189–191 In addition, autonomic function is altered by in utero exposure to SHS. Newborns whose mother smoked during pregnancy have lower heart rate variability during quiet sleep.192 Unexposed infants demonstrated increases in heart rate with head-up tilt and decreases in heart rate with head-down tilt, whereas infants exposed to SHS showed no such responses.192 Maternal smoking induces changes in autonomic maturation in infants.193 Cardiovascular stress reactivity is increased in newborn infants of active smokers.194 The resting heart rate of a smoker’s infant is lower than in a nonexposed control, most likely secondary to excessive vagal tone.23 Vagal potentiation is considered a predisposing factor in SIDS.195–197 Any smoking during pregnancy or during the first year of the infant’s life increases the risk of SIDS.186

Summary
In utero/childhood SHS exposure can result in
- Endothelial dysfunction
- Increased arterial stiffness
- Increased CIMT
- Autonomic dysfunction
- Late onset arrhythmia

BEHAVIORAL AND COMMUNITY STRATEGIES TO REDUCE/ELIMINATE SHS EXPOSURE IN CHILDREN

Individual and Population-Based Approaches
Several trials over the past 25 years have evaluated interventions aimed at reducing or eliminating SHS exposure in children. Intervention strategies fall into 2 broad groups: those that directly attempt to minimize SHS exposure to children and those that indirectly minimize children’s SHS exposure by assisting parents or caretakers to quit or reduce smoking. The majority of studies have targeted parents rather than nonparental caregivers. Interventions that directly minimized child harm from SHS used a variety of strategies, including counseling (face to face or by telephone) or provision of materials to encourage parents not to allow smoking in the home or car, not to smoke around their children, or to remove the child from rooms in the home or other locations when smoking is taking place (hygienic smoking). Other strategies include encouraging the use of air cleaners or providing biochemical feedback (as in cotinine measurement) on child SHS exposure to caregivers.

Cessation/smoking reduction interventions typically have used behavioral counseling or pharmacotherapy such as nicotine replacement. A variety of outcomes have been assessed, including self-reported behavior change related to child SHS exposure (eg, enforcement of home smoking ban, restricting smoking to designated smoking areas), self-reported smoking cessation or reduction (with or without biochemical verification), biochemical measures of children’s SHS exposure (typically cotinine assessed in urine, blood, saliva, or hair), and biochemical measures of ambient environmental tobacco smoke (usually nicotine or particulate matter) from rooms or other spaces where children are exposed.

Several literature reviews on this topic have been conducted, including nonsystematic narrative reviews,198–200 systematic narrative reviews,201,202 and systematic quantitative (ie, meta-analytic) reviews.203–206 The meta-analytic reviews include a review originally published in the Cochrane Collaboration database in 2003203 and updated in 2008204 and 2014.205 Arborelius et al198 included only interventions that occurred in pediatric practices, but other reviews did not limit the setting of interventions.

Two recent contributions205,206 were published in 2014. The Rosen et al205 systematic review included fewer studies than the Baxi et al review206 because they restricted eligibility to studies that delivered interventions to parents (not other family members, child care workers, and teachers), targeted children no older than 6 years of age (compared with 12 years of age in the Baxi et al review), and focused on interventions to help parents decrease child SHS exposure (Baxi et al also included smoking cessation programs that measured child SHS exposure as an outcome but did not have child SHS reduction as an explicit goal).

Rosen et al205 combined and analyzed effects for 3 categories of outcomes: parent-reported exposure to SHS of the child at follow-up and change from baseline to follow-up, parent-reported number of cigarettes smoked around the child at follow-up, and measured levels of cotinine in urine, blood, saliva, or hair of the child at follow-up.205 Parent-reported SHS exposure to child at follow-up was collected by 17 studies and showed a small, statistically significant effect favoring the intervention groups compared with the control group (relative risk, 1.12; 95% CI, 1.07–1.18). The risk difference was 0.07 (95% CI, 0.05–0.09), indicating that 7% of intervention families benefited on average. The effect for parent-reported exposure to SHS was positive but not statistically significant when analyzed as change from baseline to follow-up (n=7; relative risk, 1.44; 95% CI, 0.90–2.29; P=0.13).205

Parent-reported number of cigarettes to which children were exposed decreased in both the intervention and control groups but to a greater extent in the intervention group (n=8; P=0.03). Among 13 studies that used biomarkers of child SHS as the outcome, 8 studies showed positive trends, but statistical significance was reached in only 1 study. The overall risk difference

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was $-0.05$ (95% CI, $-0.13$ to $0.20$; $P=0.20$), showing a nonsignificant trend toward a small benefit of intervention. No clear benefit was demonstrated in subgroup analyses that compared studies on the basis of whether biochemical feedback was provided as an intervention strategy, intensity of the experimental intervention, intensity of the control intervention, and treatment fidelity.205

The authors concluded that interventions to reduce child SHS exposure showed “small benefits” when assessed by parent self-report, but this effect was not corroborated by objective, biochemical outcomes. It is unclear why an effect is observed for self-reported versus objective outcomes; the reason may be related to greater statistical power for parent-reported outcomes (attributable to a greater number of studies), unreliability of parent reports resulting from a lack of knowledge of their children’s exposure or intentional misreporting, or inadequate sensitivity of biomarkers to detect small changes in exposure levels.205

It is also noteworthy that many studies reported positive outcomes in control groups, which may be related to generally high levels of motivation in trial participants regardless of treatment allocation (Hawthorne effect) or to the possibility that parents reduced smoking around their children regardless of intervention (eg, because of social pressure or secular trends that make childhood SHS exposure less acceptable). Regardless, the overall conclusion is that available interventions produce, at best, small effects, and there is no empirical basis to recommend specific intervention strategies, intensities, or delivery formats.

Baxi et al206 reached similar conclusions. Among the 57 studies included in their review, 16 focused directly on minimizing child harm from SHS by changing parent/caregiver behaviors or attitudes, 20 focused exclusively on helping parents/caregivers to quit smoking or not to relapse, and 21 used a combination of these 2 intervention approaches. Effects were not quantitatively combined because of the heterogeneity of study design and characteristics. The resulting narrative review did not find evidence that any particular intervention strategies were more effective than others. Only 14 of the 57 studies found a significant intervention treatment effect, and of these, 12 were judged to have either unknown or high risk of bias. These studies used a wide range of interventions, including intensive counseling or motivational interviewing, telephone counseling, school-based strategies, picture books, and educational home visits. Similar to the Rosen et al report,205 this review found reductions in SHS exposure for children regardless of assignment to an intervention or a control group. Furthermore, there was no evidence of difference in effectiveness according to age of the target child or whether targeted children were healthy or had respiratory or other illnesses. The authors concluded that the effectiveness of interventions to reduce child SHS exposure has not been clearly demonstrated.

### Expert Panel Recommendations

The Task Force on Community Preventive Services reviewed evidence for the effectiveness of community education to reduce exposure to SHS in the home. Community education approaches included enhancing motivation or providing skills to quit or reduce smoking or implementing home policies such as bans to reduce exposure to SHS. The task force concluded207 that there was insufficient evidence to make a recommendation about the effectiveness of community education to reduce SHS exposure in the home.

A more recent expert panel208 concluded that interventions in pediatric care settings to reduce children’s SHS exposure showed mixed results. However, because of the serious public health implications of SHS, the panel recommended that pediatric healthcare providers routinely intervene. The expert panel encouraged providers to identify parents and other caregivers who smoke and explicitly recommend that children not be exposed to tobacco smoke in the home, in automobiles, and in any other space where exposure can occur. Furthermore, the expert panel concluded that parents and caregivers who smoke should be educated about the health consequences of tobacco use for the adult, the child, and (when appropriate) the fetus; encouraged to quit; and referred for smoking cessation assistance. Adding routine biochemical screening to detect metabolites of SHS as part of health promotion may identify levels of exposure different from that reported by parents.

### Effect of Smoking Bans and Taxes

Home smoking bans significantly reduce SHS exposure among children209 and may lower the likelihood that children of smokers will take up smoking.32 Unfortunately, $\approx16\%$ of smoking households did not have any restrictions against indoor smoking in 2006 to 2007,56 with a similar trend noted in 2010 to 2011,48 and children in these households were still likely to be exposed to SHS.

The effect of smoking bans in public places and their effect on children’s exposure to SHS are less clear, with some suggesting that smoking bans could potentially increase SHS exposure in children by displacing parental smoking from public places to their households. An observational study from England in 2007 by Jarvis et al210 using cotinine levels in children found no evidence of increased household exposure after the implementation of a legislative smoking ban. Adoption of smoke-free homes by smoking parents increased significantly after this ban, suggesting that it helped reinforce an emerging social norm favoring voluntary parental smoking restrictions. Similar results have been seen in the United States, where voluntary home-smoking bans were significantly more likely when community-wide, 100% smoking bans were also in effect.211
Summary

Interventional strategies that can decrease childhood SHS:

- Tobacco cessation programs are cost-effective and reduce healthcare costs.
- Home smoking bans and public smoking bans reduce childhood SHS exposure.
- Increased taxes on tobacco products reduce tobacco consumption.

FUTURE DIRECTIONS

Children exposed to SHS experience both short- and long-term adverse effects, including not only well-known respiratory complications but also cardiovascular consequences related to autonomic effects and vascular dysfunction.

Questions remain about the mechanisms by which SHS exposure is related to adverse effects in childhood. For example, infants exposed to SHS are at higher risk for SIDS, but the mechanism by which SHS exposure increases risk of SIDS is not clear. Hypotheses include altered breathing patterns and diminished autonomic variability, but more investigation is needed. Is the risk related more to in utero or postnatal SHS exposure, or are they both important? Similarly, epidemiological studies show increases in heart rate and blood pressure in children exposed to SHS. What is their clinical implication, if any, for an individual child and for the population? How do these findings integrate with the literature on long-term exposure to childhood stress, which may be an additional risk in these children? Exposure to SHS is related to dyslipidemia and metabolic syndrome. Does SHS exposure cause these changes, or are there confounding factors that mediate these relationships? Do epigenetic changes play a role? What is the impact of concomitant lifestyle factors that may also increase the risk of CVD? Adults with SHS exposure are at risk for ventricular arrhythmias, possibly related to the release of catecholamines. Does this phenomenon also occur in childhood? In all these processes, are particular components of SHS exposure to blame? Can we further tease out which components of SHS cause child-specific toxicities, particularly long-lasting ones, with a goal of minimizing or eliminating them in tobacco products as a plausible intervention?

Questions also remain with regard to the timing and durability of the adverse effects of SHS exposure. What is reversible and what is persistent? Is there a tipping point after which the cardiovascular effects persist despite elimination of SHS exposure? Are there vulnerable periods in which the effects are more pronounced or long-lasting, perhaps infancy or adolescence? What about a threshold effect? How many years of SHS exposure are needed before the vascular changes become irreversible? More information is needed with regard to mechanisms, severity of effects, whether there are vulnerable periods for exposure, and if so, when they are and whether all effects can be reversed. Despite these knowledge gaps about the mechanisms and durability by which SHS exposure in children affects the cardiovascular system, the sum of existing evidence suggests that a reduction in or an elimination of SHS exposure in childhood will improve their cardiovascular health.

Therefore, innovative methods are needed to promote behavior change to reduce and ultimately to eliminate SHS exposure using federal, state, and local policy efforts, strategies within the healthcare system, and interventions at the level of the individual. The concept of hygienic smoking, defined as a smoker being as far away as possible from others, has been proposed, and some studies suggest a benefit, mitigating long-term adverse vascular effects of childhood SHS exposure. How exactly is hygienic smoking implemented? This will be important while we are perfecting prevention and cessation efforts directed at smoking parents and close contacts with children. Does banning smoking in public places increase exposure to SHS in children at home? Adolescents report that an important component of their SHS exposure occurs outside the home. What additional interventions can be brought to bear to address this high-risk population? Interventions to reduce SHS exposure in childhood are effective when parental report is the measurement outcome, but the effect is quite small when biochemical markers of SHS are used as the outcome. How can we make a bigger impact? Future research such as SHS exposure reduction trials should include specific cardiovascular outcomes in children.

Future directions for policy makers, health systems administrators, and providers should include systematic change methods to promote cessation such as using electronic health records prompts; making cessation referral programs more easily available; training providers to be knowledgeable about best practices; working with Head Start to access parents outside the medical system; providing real-time feedback to parents about progress by way of changes in their child’s cotinine levels; focusing efforts to target high-risk, minority, and lower-SES children living in multiunit housing; providing routine biochemical screening for tobacco metabolites in high-risk children; and continuing public health campaigns to spread information about the prevailing health and economic effects of SHS exposure, particularly as they relate to children.
CONCLUSIONS

A half a century after the first US Surgeon General warning about the harmful effects of cigarette smoking, we have seen significant reductions in the incidence and prevalence of smoking and in childhood SHS exposure. Despite these changes, exposure to SHS in childhood remains high, and certain children remain especially vulnerable. On the basis of the epidemiological, observational, and experimental evidence presented here, we conclude that there are lifetime, detrimental cardiovascular consequences for children who are exposed to SHS. Investments have been made in enforcing ordinances and bans that prohibit smoking in certain locations, increasing taxes on tobacco products, and providing education and behavior modification. Overall, these efforts have had a favorable impact on reducing smoking prevalence and improving awareness of the consequences of cigarette smoking; however, young and minority children remain disadvantaged.

Healthcare providers need to emphasize and promote heart-healthy behaviors in caretakers of children at every encounter and encourage parents and caretakers to cease smoking for their own and their child's well-being. Interventions that include mass media campaigns, cigarette price increases, including those that result from tax increases, school-based policies and programs, and statewide or community-wide changes in smoke-free policies are effective in reducing the initiation, prevalence, and intensity of smoking among youth and young adults and may substantially decrease SHS exposure. The evidence presented in this statement calls for a robust public health policy that embraces zero tolerance of childhood SHS exposure.

FOOTNOTES

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

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<td>Sarah D. de Ferranti</td>
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Writing Group Disclosures continued

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<th>Speakers' Bureau/ Honoraria</th>
<th>Expert Witness</th>
<th>Ownership Interest</th>
<th>Consultant/ Advisory Board</th>
<th>Other</th>
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<td>Laura L. Benowitz</td>
<td>Stanford University</td>
<td>NIH†; Flight Attendant Medical Research Institute†; California Tobacco Related Disease Research Program†</td>
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<td>Samuel S. Gidding</td>
<td>Alfred I. duPont Hospital for Children Nemours Cardiac Center</td>
<td>NIH (TODAY study echo reading center)†</td>
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<tr>
<td>Cuno Uiterwaal</td>
<td>University Medical Center (the Netherlands)</td>
<td>Prime Agreement No. AID-OAA-A-11-00012 (collaborator in a PEER Health project, sponsored by the National Academy of Sciences and the US Agency for International Development [USAID], on the subject of maternal and offspring health effects of exposure to air pollution and SHS during pregnancy, to be initiated in Jakarta, Indonesia)*</td>
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This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be “significant” if (a) the person receives $10,000 or more during any 12-month period, or 5% or more of the person’s gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $10,000 or more of the fair market value of the entity. A relationship is considered to be “modest” if it is less than “significant” under the preceding definition.

*Modest.
†Significant.

Reviewer Disclosures

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<td>Neal L. Benowitz</td>
<td>Stanford University</td>
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†Significant.
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Cardiovascular Consequences of Childhood Secondhand Tobacco Smoke Exposure: Prevailing Evidence, Burden, and Racial and Socioeconomic Disparities: A Scientific Statement From the American Heart Association

Geetha Raghuveer, David A. White, Laura L. Hayman, Jessica G. Woo, Juan Villafane, David Celermajer, Kenneth D. Ward, Sarah D. de Ferranti, Justin Zachariah and On behalf of the American Heart Association Committee on Atherosclerosis, Hypertension, and Obesity in the Young of the Council on Cardiovascular Disease in the Young; Behavior Change for Improving Health Factors Committee of the Council on Lifestyle and Cardiometabolic Health and Council on Epidemiology and Prevention; and Stroke Council

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儿童暴露于二手烟的心血管影响：流行学证据、负担、种族和社会经济差异

美国心脏协会科学声明

在过去的50年里，美国的医疗服务提供者和公共卫生专业人员已经加强了对健康风险和吸烟相关联的意识。虽然公共卫生项目已使得吸烟的普遍率大大降低，但是暴露于吸烟的不良健康反应仍有发生。在美国，每10名学龄儿童中有4个是不自觉地暴露于二手烟（SHS）的，而每3个青少年中亦有1个这样的情况（图1），少数族裔的孩子和那些生活在低社会经济地位的家庭有不同的程度的影响（分别为88%和43%）。孩子们特别脆弱，几乎不能控制家庭和社会环境，并且缺乏理解、代理和能力来以自己的意志避免暴露于SHS；同时他们生理或行为上特征使他们特别容易受到SHS的影响。侧流烟（来自香烟燃烧端飘来的烟雾），作为SHS的主要组成部分，含有比主流烟（直接被吸烟者吸入）更高浓度的一些毒素，这使得SHS与直接吸烟比起来可能同样危险或更危险。著名的动物和人类证据表明，儿童时期接触SHS对动脉功能和结构是有害的，导致过早动脉粥样硬化及其心血管的影响。此外，儿童暴露于SHS还与心血管代谢风险因素群相关，例如肥胖、血脂异常、胰岛素抵抗。个性化干预以减少儿童暴露于SHS证实至少是有一定效果的，而广泛的社会政策也同样有效，例如社区禁烟和增加税收。

该声明的目的是总结童年暴露于SHS的心血管影响的现有证据；这将进一步支持正在进行的有关减少和消除SHS暴露于这些脆弱群体的努力。该声明综述了有关SHS和儿童心血管疾病风险的流行病学研究、基于实验的试验以及行为控制试验的相关数据。检查了SHS暴露对动物和儿童心血管系统的影响的研究信息，包括血管破坏和血小板活化、氧化和炎症、血管内皮功能障碍、血管硬度增加、血管结构的变化，以及自主功能的障碍。

图1. 非吸烟（A）美国3-11岁儿童以及（B）美国12-19岁青少年的患病率和二手烟（SHS）暴露的估计来源，来自国家健康和营养调查（NHANES）研究年份。

迄今为止累积的流行病学、观察和实验证据表明儿童暴露于SHS的有害心血管影响。加强对儿童暴露于SHS的危害和终身心血管影响的意识，可以促进改善，激励个体、家庭和社区卫生干预措施，以减少并在理想情况下消除SHS暴露在脆弱儿童人群中的状况。该证据号召一个健全的公共卫生政策来维护童年SHS暴露的零容忍。

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