Effects of Nonlipid Risk Factors on Atherosclerosis in Youth
With a Favorable Lipoprotein Profile

Henry C. McGill, Jr, MD; C. Alex McMahan, PhD; Arthur W. Zieske, MD; Gray T. Malcom, PhD; Richard E. Tracy, MD, PhD; Jack P. Strong, MD; for the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) Research Group

Background—The strong association between coronary heart disease and dyslipoproteinemia has often overshadowed the effects of the nonlipid risk factors—smoking, hypertension, obesity, and diabetes and impaired glucose tolerance—and even led to questioning the importance of these risk factors in the presence of a favorable lipoprotein profile.

Methods and Results—A cooperative multicenter study, the Pathobiological Determinants of Atherosclerosis in Youth (PDAY), examined the relation of the nonlipid risk factors to atherosclerosis in 629 men and 227 women 15 to 34 years of age who died of external causes and who had a favorable lipoprotein profile (non-HDL cholesterol < 4.14 mmol/L [<160 mg/dL] and HDL cholesterol ≥ 0.91 mmol/L [≥35 mg/dL]). In the abdominal aorta, smokers had more extensive fatty streaks and raised lesions than nonsmokers, and hypertensive blacks had more raised lesions than normotensive blacks. In the right coronary artery, hypertensive blacks had more raised lesions than normotensive blacks, obese men (body mass index ≥ 30 kg/m²) had more extensive fatty streaks and raised lesions than nonobese men, and individuals with impaired glucose intolerance had more extensive fatty streaks. Obese men had more severe lesions (American Heart Association grade 2 through 5) of the left anterior descending coronary artery.

Conclusions—These substantial effects of the nonlipid risk factors on the extent and severity of coronary and aortic atherosclerosis, even in the presence of a favorable lipoprotein profile, support the need to control all cardiovascular risk factors. (Circulation. 2001;103:1546-1550.)

Key Words: coronary disease ■ risk factors ■ atherosclerosis

Methods

Study Design
Fifteen cooperating centers adopted standardized methods to collect specimens and data and to analyze them in central laboratories.

Subjects
Study subjects were persons 15 through 34 years of age who died of external causes (accidents, homicides, or suicides) within 72 hours of injury and were autopsied within 48 hours of death in one of the cooperating forensic laboratories. Age and race were obtained from the death certificate. We collected 2876 acceptable cases from June 1, 1987, to August 31, 1994. Data on all risk factors were available for 1479 cases. The Institutional Review Board of each cooperating center approved this study.

Dissecting and Preserving Arteries
PDAY investigators bisected the aorta longitudinally and fixed the left half in 10% neutral buffered formalin. They opened the right coronary artery (RCA) longitudinally and fixed it in the same manner. They perfused the left main artery and left anterior descending coronary artery (LAD) with 10% buffered formalin at a pressure of ~100 mm Hg (130 cm H₂O) and dissected them from the heart. A
TABLE 1  Nonlipid Risk Factors, Samples, Analyses, Risk Classification Criteria, Prevalence of Risk Factors in All PDAY Cases, and Prevalence in Cases With a Favorable Lipoprotein Profile

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Sample</th>
<th>Analysis</th>
<th>Criterion for Presence of Risk Factor</th>
<th>Prevalence in PDAY cases, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking</td>
<td>Serum</td>
<td>Thiocyanate</td>
<td>≥90 μmol/L</td>
<td>44.0</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Renal arteries</td>
<td>Intimal thickness and algorithm to estimate mean arterial pressure</td>
<td>≥110 mm Hg</td>
<td>15.5</td>
</tr>
<tr>
<td>Obesity</td>
<td>Measured at autopsy</td>
<td>Body mass index</td>
<td>≥30 kg/m²</td>
<td>14.3</td>
</tr>
<tr>
<td>Impaired glucose tolerance</td>
<td>Red blood cells</td>
<td>% Glycohemoglobin</td>
<td>≥8%</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Results

Prevalence of Lipid and Nonlipid Risk Factors
Table 1 gives the prevalence of nonlipid risk factors in all PDAY subjects and the prevalence of nonlipid risk factors among subjects with a favorable lipoprotein profile. Of the individuals with a favorable lipoprotein profile, 38.8% had no nonlipid risk factors; 47.3% had 1 nonlipid risk factor, of whom 68.6% were smokers; 13.1% had 2 nonlipid risk factors (smoking and hypertension were the most prevalent combination); 0.7% had 3 nonlipid risk factors; and 0.1% had all 4 nonlipid risk factors.

Effect of Nonlipid Risk Factors on Gross Lesions
Table 2 gives the effects of nonlipid risk factors on fatty streaks and raised lesions in the presence of a favorable lipoprotein profile. The effects are presented as the ratio of extent involvement at the high level of a risk factor (as defined in Table 1) to the extent involvement at the desirable level of a risk factor. Men had less extensive fatty streaks than women (ratio <1.0) in the abdominal aorta, but men and women had about an equal extent of raised lesions. In contrast, although men had only slightly more extensive fatty streaks in the RCA than women (ratios slightly >1.0, P=NS), they developed considerably more extensive raised lesions in both the 15- to 24-year-old and 25- to 34-year-old age groups.

Smoking was associated with more extensive fatty streaks in the abdominal aorta in both the 15- to 24-year-old and 25- to 34-year-old age groups and with a much greater extent of raised lesions in the abdominal aorta of 25- to 34-year-old subjects. It had little effect on the extent of either type of lesion in the RCA.

Hypertension was associated with a greater extent of raised lesions in the abdominal aorta and RCA of blacks. Hypertension tended to be associated with more extensive raised lesions in whites, but the effect was smaller than in blacks of the same age. We believe that the ratio of 0.55 for raised lesions in the abdominal aorta of younger whites is due to the low prevalence of hypertension in the younger age group and does not represent a real effect of hypertension. Hypertension was not associated with fatty streaks in either whites or blacks.

Obesity was associated with more extensive fatty streaks in the RCAs of 15- to 24-year-old men and with more extensive raised lesions in both 15- to 24-year-old and 25- to 34-year-olds, with women having less extensive fatty streaks than men. Elevated mean arterial pressure of 110 mm Hg tended to be associated with more extensive raised lesions in both 15- to 24-year-old and 25- to 34-year-olds. Men had less extensive fatty streaks than women (ratio <1.0) in the abdominal aorta, but men and women had about an equal extent of raised lesions. In contrast, although men had only slightly more extensive fatty streaks in the RCA than women (ratios slightly >1.0, P=NS), they developed considerably more extensive raised lesions in both the 15- to 24-year-old and 25- to 34-year-old age groups.

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old men. Obesity was not associated with either fatty streaks or raised lesions in the RCAs or aortas of women.

Elevated glycohemoglobin was associated with more extensive fatty streaks in the RCAs of 15- to 24-year-old men and women, but the associations with raised lesions were not significant, probably because of the low prevalence of elevated glycohemoglobin.

Effects of Nonlipid Risk Factors on Microscopic Characteristics of Lesions

Eighteen (4.2%) of 430 cases had AHA grade 4 to 5 (advanced) lesions in the LAD. One of the women with a grade 4 to 5 lesion had no risk factors, and 3 had 1 risk factor. Three of the men with a grade 4 to 5 lesion had no risk factors, 5 had 1 risk factor, and 6 had 2 risk factors. Table 3 shows the odds ratios for AHA grades 2 to 5 (fatty streaks and advanced lesions) versus AHA grades 0 to 1 (normal and isolated foam cells). All of the odds ratios (except that for smoking) were substantially >1.0, and the odds ratios for male sex and obesity in men were statistically significant. The lack of statistical significance is probably due to the limited number of cases.

Effect of Combined Risk Factors

The Figure compares the extent of raised lesions in the RCAs of persons who did not smoke, were normotensive, were not

### Table 2

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Male sex</td>
<td>All</td>
<td>Fatty streaks</td>
<td>0.82±0.11*</td>
<td>0.66±0.11*</td>
<td>1.20±0.20</td>
<td>1.13±0.19</td>
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<tr>
<td></td>
<td></td>
<td>Raised lesions</td>
<td>1.01±0.22</td>
<td>0.87±0.22</td>
<td>1.73±0.29*</td>
<td>1.89±0.31*</td>
</tr>
<tr>
<td>Smoking</td>
<td>All</td>
<td>Fatty streaks</td>
<td>1.20±0.07*</td>
<td>1.20±0.07*</td>
<td>1.04±0.14</td>
<td>0.97±0.15</td>
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<tr>
<td></td>
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<td>Raised lesions</td>
<td>1.17±0.18</td>
<td>2.75±0.51*</td>
<td>1.06±0.15</td>
<td>1.11±0.15</td>
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<tr>
<td>Hypertension</td>
<td>Whites</td>
<td>Fatty streaks</td>
<td>0.99±0.13</td>
<td>0.94±0.12</td>
<td>1.26±0.34</td>
<td>1.32±0.36</td>
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<td></td>
<td></td>
<td>Raised lesions</td>
<td>0.55±0.37*</td>
<td>0.74±0.26</td>
<td>1.09±0.28</td>
<td>1.44±0.38</td>
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<td>Blacks</td>
<td>Fatty streaks</td>
<td>1.06±0.09</td>
<td>1.01±0.06</td>
<td>1.08±0.21</td>
<td>1.12±0.18</td>
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<td></td>
<td></td>
<td>Raised lesions</td>
<td>1.19±0.26</td>
<td>1.51±0.29*</td>
<td>1.51±0.32*</td>
<td>1.98±0.41*</td>
</tr>
<tr>
<td>Obesity</td>
<td>Men</td>
<td>Fatty streaks</td>
<td>1.09±0.12</td>
<td>1.15±0.13</td>
<td>2.20±0.53*</td>
<td>1.30±0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raised lesions</td>
<td>0.98±0.26</td>
<td>0.87±0.25</td>
<td>1.87±0.47*</td>
<td>1.92±0.43*</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>Fatty streaks</td>
<td>0.96±0.14</td>
<td>1.01±0.13</td>
<td>1.29±0.41</td>
<td>0.74±0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raised lesions</td>
<td>0.97±0.36</td>
<td>0.87±0.32</td>
<td>1.08±0.35</td>
<td>1.13±0.34</td>
</tr>
<tr>
<td>Elevated glycohemoglobin</td>
<td>All</td>
<td>Fatty streaks</td>
<td>0.97±0.17</td>
<td>0.91±0.12</td>
<td>2.13±0.73*</td>
<td>1.22±0.40</td>
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<tr>
<td></td>
<td></td>
<td>Raised lesions</td>
<td>0.83±0.36</td>
<td>0.91±0.29</td>
<td>1.40±1.50</td>
<td>1.21±0.39</td>
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</table>

*Ratios significantly different from 1.00 (P<0.05).

### Table 3

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Group</th>
<th>Number With Risk Factor</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male sex</td>
<td>All</td>
<td>311</td>
<td>4.09 (1.71–9.81)*</td>
</tr>
<tr>
<td>Smoking</td>
<td>All</td>
<td>253</td>
<td>0.99 (0.60–1.62)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>All</td>
<td>78</td>
<td>1.22 (0.67–2.24)</td>
</tr>
<tr>
<td>Obesity</td>
<td>Men</td>
<td>37</td>
<td>3.72 (1.73–8.04)*</td>
</tr>
<tr>
<td>Obesity</td>
<td>Women</td>
<td>20</td>
<td>0.31 (0.06–1.52)</td>
</tr>
<tr>
<td>Elevated glycohemoglobin</td>
<td>All</td>
<td>20</td>
<td>1.78 (0.64–4.96)</td>
</tr>
</tbody>
</table>

*95% CIs that do not include 1.00.
obese, and had normal glycohemoglobin with the extent of raised lesions in persons who smoked, were hypertensive, were obese, and had elevated glycohemoglobin. All had a favorable lipoprotein profile. The differences were substantial, even in the 15- to 19-year-old age group and in both men and women. Differences became greater in succeeding age groups and were 5-fold higher in men aged 30 to 34 years. These risk factor profiles illustrate the extreme profiles of no risk factors and all risk factors. The extent of raised lesions for other profiles will be intermediate.

**Discussion**

**Summary of Results**

The nonlipid risk factors—smoking, hypertension, obesity, and impaired glucose tolerance—accelerate atherogenesis in the presence of a favorable lipoprotein profile in young people. Hence, an unfavorable lipoprotein profile is not a necessary condition for progression of atherosclerosis in young people. Control of dyslipidemia alone will undoubtedly retard the progression of atherosclerosis in young persons, but there will remain a substantial atherogenic stimulus from smoking, hypertension, obesity, and hyperglycemia.

**Male Sex**

Although male sex is not among the mutable risk factors, the results presented here emphasize the more rapid progression of coronary atherosclerosis in young men than in young women. This difference is not explained by established risk factors. The difference between young men and young women in atherosclerotic lesions precedes the difference between the sexes in clinical CHD at older ages. This observation is consistent with the concept that risk factor reduction in young people will prevent or delay the development of clinical CHD.

**Smoking**

The strongest effect of smoking is on a localized region of the dorsolateral aspect of the distal third of the abdominal aorta. The effect is evident in the late teenage years and becomes stronger in later decades. This finding is consistent with the well-established association of smoking with abdominal aortic aneurysm. Smoking is associated with a higher microscopic grade of coronary artery fatty streaks in young people, but a stronger effect on raised lesions becomes evident after age 35. Smoking is associated with increased risk of clinical CHD in the presence of low serum cholesterol levels, a finding consistent with the results reported here.

**Hypertension**

In the PDAY study, hypertension was the only risk factor that affected raised lesions but not fatty streaks. This effect remained strong in the presence of a favorable lipoprotein profile. As in previous analyses of these cases, the effect was stronger in blacks, probably due to the greater severity of hypertension in blacks.

**Obesity**

Obesity is the only risk factor in the PDAY study that affects atherosclerotic lesions in men but not in women. Its effect is not explained by other risk factors. The present results show that obesity does not depend on the presence of an unfavorable lipoprotein profile to accelerate atherogenesis.

**Impaired Glucose Tolerance**

In a previous analysis of PDAY cases, elevated glycohemoglobin was associated with a significant 3-fold excess of raised lesions in the RCAs of persons 15 to 24 years of age and a 5-fold excess in persons 25 to 34 years of age, even when adjusted for other risk factors. In this smaller number of cases with a favorable lipoprotein profile, the effect was significant only for RCA fatty streaks. The ratios (Table 2) for raised lesions were greater than 1.0 but not significantly greater, probably because the number of cases having elevated glycohemoglobin was too small.

**Limitations of Study**

Because emergency medical teams often administer large quantities of intravenous fluids to some individuals immediately before death from violent causes, we excluded serum values from cases having total cholesterol <2.59 mmol/L (100 mg/dL). The selection of desirable lipoprotein profiles having non-HDL cholesterol and HDL cholesterol concentrations at opposite ends of the distributions also minimizes the potential effects of hemodilution. Although agonal procedures may degrade associations, we do not believe that they are likely to produce spurious associations.

**Comparison With Other Studies**

The effects of the nonlipid risk factors reported here are consistent with the risk factor effects estimated from all PDAY cases. Those analyses did not indicate interactions between the lipid and nonlipid risk factors. Because those analyses used a larger number of cases, some risk factor effects were statistically significant, whereas effects of similar magnitude were not statistically significant in the smaller number of cases analyzed for the present report. The Bogalusa Heart Study examined the effects of multiple risk factors on atherosclerosis in 93 young persons between 2 and 39 years of age (average ~20 years). The severity of atherosclerosis increased as the number of risk factors increased, but the authors did not analyze the effects of nonlipid risk factors in the presence of a favorable lipoprotein profile.

**Prevalence of Nonlipid Risk Factors**

Table 1 shows a high prevalence of nonlipid risk factors among these young people having a favorable lipoprotein profile. The high prevalence of smoking in PDAY cases (44%) is consistent with recent reports of prevalence of smoking among high school students and young adults, with the prevalence being highest (28.7%) among persons 18 to 24 years old. PDAY cases showed an even higher prevalence because we used an objective marker of smoking and because there is an association of smoking with high-risk behaviors that predispose those who smoke to traumatic death.

The prevalence of hypertension among young white and black men and women observed in PDAY is consistent with prevalence of hypertension observed in a living population. Although only ~4% of PDAY cases had glycohemoglobin...
Implications for Prevention of CHD

The high prevalence of nonlipid risk factors indicates considerable potential to affect early atherosclerosis and subsequent CHD by modifying these risk factors even among those young people with a favorable lipoprotein profile. Changing the behavior of young people to reduce cardiovascular risk is a serious challenge and a difficult task. Efforts to modify diet in children by intervention in school lunch programs and by family counseling have achieved only limited success.23,24 The decline in adolescent and youth smoking since 1974 slowed after 1985 and now is reversed.25 Obesity is emerging as a major health problem.26

Despite the controversy over screening for blood cholesterol, diet modification, and drug treatment at early ages, there is little or no controversy over hygienic measures to control smoking, obesity, hypertension, and hyperglycemia in young persons. As demonstrated in the results presented here, these nonlipid risk factors substantially affect the extent and severity of coronary and aortic atherosclerosis even in individuals with a favorable lipoprotein profile. The earlier all the cardiovascular risk factors are controlled, as recommended by the AHA in 1992,27 the greater the potential for deflecting the onset of CHD.

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References


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