GENETIC VARIATION IN ALCOHOL DEHYDROGENASE AND THE BENEFICIAL EFFECT OF MODERATE ALCOHOL CONSUMPTION ON MYOCARDIAL INFARCTION


ABSTRACT

Background A polymorphism in the gene for alcohol dehydrogenase type 3 (ADH3) alters the rate of alcohol metabolism. We investigated the relation among the ADH3 polymorphism, the level of alcohol consumption, and the risk of myocardial infarction in a nested case-control study based on data from the prospective Physicians’ Health Study.

Methods We identified 396 patients with eligible newly diagnosed cases of myocardial infarction among men in the Physicians’ Health Study. Of these patients, 374 were matched with 2 randomly selected control subjects each and the remaining 22 with 1 control each (total, 770 controls). The ADH3 genotype (γ1γ2, γ1γ2, or γ2γ2) was determined in all subjects. We examined the relations among the level of alcohol intake, the ADH3 genotype, and plasma high-density lipoprotein (HDL) levels in this study population and in a similar cohort of women.

Results As compared with homozygosity for the allele associated with a fast rate of ethanol oxidation (γ1), homozygosity for the allele associated with a slow rate of ethanol oxidation (γ2) was associated with a reduced risk of myocardial infarction (relative risk, 0.65; 95 percent confidence interval, 0.43 to 0.99). Moderate alcohol consumption was associated with a decreased risk of myocardial infarction in all three genotype groups (γ1γ2, γ1γ2, and γ2γ2); however, the ADH3 genotype significantly modified this association (P=0.01 for the interaction). Among men who were homozygous for the γ2 allele, those who consumed at least one drink per day had a reduced risk of myocardial infarction of 0.62 (95 percent confidence interval, 0.34 to 1.13), as compared with the risk among men who consumed less than one drink per week. Men who consumed at least one drink per day and were homozygous for the γ2 allele had the greatest reduction in risk (relative risk, 0.14; 95 percent confidence interval, 0.04 to 0.45). Such men also had the highest plasma HDL levels (P for interaction = 0.05). We confirmed the interaction among the ADH3 genotype, the level of alcohol consumption, and the HDL level in an independent study of postmenopausal women (P = 0.02).

Conclusions Moderate drinkers who are homozygous for the slow-oxidizing ADH3 allele have higher HDL levels and a substantially decreased risk of myocardial infarction. (N Engl J Med 2001;344:549-55.)

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and plasma levels of high-density lipoproteins (HDLs)
in a group of men and in a similar cohort of women.

METHODS

Study Design

In 1982, the Physicians’ Health Study commenced as a randomiz-
ed, double-blind, placebo-controlled trial of aspirin and beta car-
etene among 22,071 U.S. male physicians between the ages of 40
and 84 years who had no history of myocardial infarction or stroke.14
Informed consent was obtained from all subjects, and the research
protocol was approved by the institutional review board at Brigham
and Women’s Hospital in Boston. Before randomization, each sub-
ject was asked to provide a blood sample. Specimens were received
from 14,916 (68 percent) of the physicians, who form the base-line
cohort for this study; collection methods have been described else-
where.15 At the time of blood sampling, information was also col-
clected on risk factors for cardiovascular disease.

The men were followed by means of annual mailed question-
naires. We sought the medical records of all men who reported a
myocardial infarction so as to confirm that the event met World
Health Organization criteria.16 Sudden deaths that were not con-
firmed as being due to coronary disease and silent infarcts were ex-
cluded. We routinely obtained information on the cause of death
from death certificates, medical records, and autopsy reports. fol-
low-up data on fatal and nonfatal outcomes were obtained for 99
percent of the subjects.

By 1994, 396 men with eligible cases of myocardial infarction had
been identified. We attempted to match each patient to two control
subjects who were free of myocardial infarction at the time of the
diagnosis of myocardial infarction in the patient. Control subjects
were randomly selected from among the subjects who sent blood
samples and were matched to the patient for age (within one year),
smoking status (never smoked, past smoking, or current smoking),
and time since randomization (according to six-month intervals).
Controls were selected randomly from the same population from
which the patients were derived in order to minimize the chance of
false positive results due to population stratification (i.e., the selec-
tion of controls from a population with a different prevalence of
alleles than that of the population of patients). In the case of 22
patients, we could identify only 1 control who met the matching
criteria, yielding a total of 1166 subjects (396 patients and 770 con-
trols).

We assessed the relation among the ADH3 genotype, the level of
alcohol consumption, and plasma levels of HDL in an independent
study of 325 postmenopausal women who were not taking hor-
monal replacement therapy. These women were participants in a
nested case–control study of breast cancer among the 33,826 sub-
jects in the Nurses’ Health Study who had donated blood in the pe-
riod from 1989 through 1990, as described elsewhere.17

Laboratory Analysis

We used the polymerase-chain-reaction assay and restriction-frag-
ment–length polymorphism analysis to determine in a blinded fash-
on the ADH3 genotype of each subject.18 Both negative and posi-
tive controls were included. Total cholesterol and HDL cholesterol
were measured in the Lipid Research Laboratory of Brigham and
Women’s Hospital, as described previously.19

Statistical Analysis

We used a chi-square test to determine whether the ADH3 gen-
otypes were in Hardy–Weinberg equilibrium.20 We used condition-
al logistic regression to estimate the multivariate relative risks (and
interaction terms for each category of alcohol consumption and each
ADH3 genotype). To test for interactions between the level of alco-
hol consumption and the ADH3 genotype, we used a likelihood-
ratio test to compare nested models that included terms for all com-
binations of the ADH3 genotype and levels of alcohol consumption
with models without such terms. The P value for trend was based
on the Wald test.

We also assessed whether the ADH3 genotype modified the re-
lation between the level of alcohol consumption and HDL levels.
We used mixed regression models to calculate the mean adjusted
HDL levels. One patient whose HDL level was more than three in-
terquartile ranges above the median was excluded. In addition to the
previously mentioned risk factors for myocardial infarction, we also
adjusted for age (as a continuous variable) and smoking status
(never, past, or current). For the analyses of 325 women from the
Nurses’ Health Study, we adjusted for age (<61.5 or $61.5 years),
body-mass index (22, 22 to <25, 25 to <29, or $29), whether
or not blood had been obtained after an overnight fast, whether or
not hormone-replacement therapy had been used in the past, and
pack-years of smoking (to 1990). Because the average levels of al-
cohol consumption were lower among the women than among the
men, the categories of alcohol consumption were dichotomized
(<half a drink per day [<7 g per day] or $half a drink per day
[7 g per day]). Tests for interaction and trend were determined
as described previously.

RESULTS

As compared with the control subjects, patients who
had a myocardial infarction had a higher preva-
ce of diabetes (P = 0.01), angina (P < 0.001), and
hypertension (P < 0.001) and were more likely to have
a parent who had had a myocardial infarction before
the age of 60 years (P = 0.05). In addition, patients
consumed less alcohol (P = 0.02), participated less of-
ten in vigorous exercise (P = 0.002), and had higher
total cholesterol levels (P < 0.001) and lower HDL lev-
els (P < 0.001).

Among the 14,916 study subjects who provided blood at base line, 93 percent were white. The fre-
cuencies of ADH3 alleles among the control subjects
in this study population were 60 percent for the $g
allele and 40 percent for the $g allele, results that
were consistent with previously reported estimates for
whites.7 The distribution of ADH3 genotypes among
the controls was in Hardy–Weinberg equilibrium (P =
0.47). The percentage of controls in each genotype
subgroup who consumed at least one drink per day
was similar: 30 percent among those who were homo-
zygous for the $g allele ($gc), 32 percent among those


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who were heterozygous ($\gamma_1\gamma_2$), and 29 percent among those who were homozygous for the $\gamma_2$ allele ($\gamma_2\gamma_2$).

As previously reported in this cohort, we found a lower risk of myocardial infarction among men who consumed alcohol daily than among those with lower levels of alcohol intake. As compared with men who consumed less than one drink per week, men who consumed at least one drink per week but less than one drink per day had a multivariate relative risk of myocardial infarction of 0.96 (95 percent confidence interval, 0.70 to 1.32) and men who consumed at least one drink per day had a relative risk of 0.62 (95 percent confidence interval, 0.43 to 0.91) (P for trend=0.02).

We observed a reduction in the risk of myocardial infarction among men with at least one $\gamma_2$ allele. As compared with men who were homozygous for the $\gamma_1$ allele, men who were heterozygous had a multivariate relative risk of 0.83 (95 percent confidence interval, 0.62 to 1.11) and men who were homozygous for the $\gamma_2$ allele had a relative risk of 0.65 (95 percent confidence interval, 0.43 to 0.99) (Table 1). In the multivariate analysis, the trend toward a decreasing relative risk from the $\gamma_1\gamma_1$ group to the $\gamma_2\gamma_2$ group was statistically significant (P for trend=0.04). The multivariate relative risks were not affected by adjustment for the level of alcohol consumption.

The $ADH3$ genotype significantly modified the effect of the level of alcohol consumption on the risk of myocardial infarction (P=0.01 by the likelihood-ratio test) (Table 2). As compared with the reference group of men who consumed less than one drink per week and who were homozygous for the $\gamma_1$ allele, men who consumed one or more drinks per day had a reduced risk of myocardial infarction regardless of their $ADH3$ genotype. However, the reduction in risk was largest (86 percent) among the subgroup of men who drank daily and who were homozygous for the $\gamma_2$ allele (multivariate relative risk, 0.14; 95 percent confidence interval, 0.04 to 0.45). A reduction in the risk of myocardial infarction was also observed in the subgroup of men who consumed less than one drink per week and who were homozygous for the $\gamma_2$ allele; however, this reduction was not statistically significant (multivariate relative risk, 0.59; 95 percent confidence interval, 0.28 to 1.23; P=0.16). When the level of alcohol consumption was dichotomized (≥1 drinks per day or <1 drink per day), the risk of myocardial infarction was lowest among the men who consumed at least one drink per day and who were homozygous for the $\gamma_2$ allele (Fig. 1).

There was no evidence to suggest a three-way interaction among the $ADH3$ genotype, the level of alcohol consumption, and the use of aspirin treatment on the risk of myocardial infarction among the patients in whom a myocardial infarction occurred before January 1988, when the aspirin component of the trial was terminated (and their matched controls) (P=0.60).

We also assessed the relation among $ADH3$ genotype, the level of alcohol consumption, and plasma levels of HDL among 385 patients and 385 controls;

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**Table 1. Relative Risks of Myocardial Infarction According to the $ADH3$ Genotype.**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>$ADH3$ GENOTYPE</th>
<th>P VALUE*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma_1\gamma_1$</td>
<td>$\gamma_1\gamma_2$</td>
</tr>
<tr>
<td>No. of subjects (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients</td>
<td>161 (41)</td>
<td>184 (46)</td>
</tr>
<tr>
<td>Controls</td>
<td>279 (36)</td>
<td>361 (47)</td>
</tr>
<tr>
<td>Relative risk (95% CI)†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matched</td>
<td>1.0‡</td>
<td>0.90 (0.69–1.17)</td>
</tr>
<tr>
<td>Multivariate</td>
<td>1.0‡</td>
<td>0.81 (0.61–1.09)</td>
</tr>
<tr>
<td>Multivariate, with adjustment for alcohol consumption§</td>
<td>1.0‡</td>
<td>0.83 (0.62–1.11)</td>
</tr>
</tbody>
</table>

*The P value is for the test for trend.
†In the matched analysis, patients and controls were matched for age (within one year), smoking status (never smoked, past smoking, or current smoking), and time since randomization (in six-month intervals). In the multivariate analyses, in addition to adjustment for age, smoking status, and time since randomization, the analyses were adjusted for body-mass index (<25.01, 23.01 to 24.40, >24.40 to 26.40, or >26.40), frequency of vigorous physical activity (<1, 1 to 4, or ≥5 times per week), presence or absence of a family history of myocardial infarction, presence or absence of a recent history of hypertension, diabetes, and angina at enrollment. Four patients and two controls who were taking medication for high cholesterol levels were excluded. CI denotes confidence interval.
‡This group served as the reference group.
§The categories of alcohol consumption were as follows: <1 drink per week, ≥1 drinks per week but <1 drink per day, and ≥1 drinks per day. One patient and five controls were excluded because of missing information on alcohol consumption.
HDL levels were not measured for the other controls. For all three \textit{ADH3} genotypes, the mean adjusted HDL level among men who had at least one drink per day (47.4 mg per deciliter [1.2 mmol per liter]) was 3.5 mg per deciliter (0.09 mmol per liter) higher than that among men who consumed less than one drink per day (43.9 mg per deciliter [1.1 mmol per liter], \(P=0.002\). When the HDL levels were analyzed according to the \textit{ADH3} genotype, the mean adjusted HDL levels were higher among men who consumed at least one drink per day in all three genotype groups (Fig. 2A). However, among these men, HDL levels were highest among those who were homozygous for the \(\gamma_2\) allele, intermediate among the heterozygotes, and lowest among those who were homozygous for the \(\gamma_1\) allele (\(P=0.05\) for the interaction between the level of alcohol consumption and the genotype on the HDL level). The trend in the HDL level among the genotypes in the group of men who consumed at least one drink per day was significant (\(P\) for trend = 0.007).

The \textit{ADH3} genotype appeared to have no effect on the HDL levels among the men who consumed less than one drink per day. Among the men whose HDL levels were measured, the significant reduction in the risk of myocardial infarction associated with homozygosity for the \(\gamma_2\) allele was still present after adjustment for HDL levels. As compared with men who consumed less than one drink per week and who were homozygous for the \(\gamma_1\) allele, men who consumed at least one drink per day and who were homozygous for the \(\gamma_2\) allele had a multivariate relative risk of myocardial infarction of 0.15 (95 percent confidence interval, 0.05 to 0.46) before adjustment for baseline HDL levels and a risk of 0.23 (95 percent confidence interval, 0.07 to 0.77) after adjustment.

We found a similar relation among the \textit{ADH3} genotype, the level of alcohol consumption, and plasma levels of HDL among 325 postmenopausal women who were not receiving hormone-replacement therapy in the Nurses’ Health Study. Overall, the mean adjusted HDL level among women who consumed at least 7 g of alcohol per day (approximately half a drink) was 7.8 mg per deciliter (0.2 mmol per liter) higher than the level among women who consumed less than 7 g of alcohol per day (64.1 vs. 56.3 mg per deciliter [1.7 vs. 1.5 mmol per liter], \(P<0.001\)). The HDL levels were not measured for the other controls.

### TABLE 2. RELATIVE RISKS OF MYOCARDIAL INFARCTION ACCORDING TO THE \textit{ADH3} GENOTYPE AND THE LEVEL OF ALCOHOL CONSUMPTION.*

<table>
<thead>
<tr>
<th>LEVEL OF ALCOHOL CONSUMPTION</th>
<th>(\gamma_1) GENOTYPE</th>
<th>(\gamma_1) GENOTYPE</th>
<th>(\gamma_1) GENOTYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&lt;1) Drink per week</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>50</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>No. of controls</td>
<td>78</td>
<td>82</td>
<td>43</td>
</tr>
<tr>
<td>Relative risk (95% CI)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matched</td>
<td>1.0</td>
<td>0.96 (0.58–1.61)</td>
<td>0.66 (0.34–1.31)</td>
</tr>
<tr>
<td>Multivariate</td>
<td>1.0</td>
<td>1.01 (0.58–1.75)</td>
<td>0.59 (0.28–1.23)</td>
</tr>
<tr>
<td>(\geq1) Drinks per week but (&lt;1) drink per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>80</td>
<td>82</td>
<td>29</td>
</tr>
<tr>
<td>No. of controls</td>
<td>115</td>
<td>163</td>
<td>49</td>
</tr>
<tr>
<td>Relative risk (95% CI)†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matched</td>
<td>1.06 (0.66–1.69)</td>
<td>0.77 (0.49–1.21)</td>
<td>0.97 (0.55–1.72)</td>
</tr>
<tr>
<td>Multivariate</td>
<td>1.11 (0.67–1.84)</td>
<td>0.66 (0.40–1.08)</td>
<td>1.02 (0.55–1.88)</td>
</tr>
<tr>
<td>(\geq1) Drinks per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>30</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>No. of controls</td>
<td>84</td>
<td>114</td>
<td>37</td>
</tr>
<tr>
<td>Relative risk (95% CI)‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matched</td>
<td>0.55 (0.31–0.97)</td>
<td>0.72 (0.44–1.18)</td>
<td>0.23 (0.08–0.62)</td>
</tr>
<tr>
<td>Multivariate</td>
<td>0.62 (0.34–1.13)</td>
<td>0.68 (0.40–1.15)</td>
<td>0.14 (0.04–0.45)</td>
</tr>
</tbody>
</table>

*\(P=0.01\) by the likelihood ratio test for the interaction between the \textit{ADH3} genotype and the level of alcohol consumption after adjustment for the factors used for matching and the listed risk factors.

†One patient and five control subjects were excluded because of missing data on alcohol consumption. In the matched analysis, patients and controls were matched for age (within one year), smoking status, and time since randomization (in six-month intervals). In the multivariate analysis, in addition to adjustment for age, smoking status (never smoked, past smoking, or current smoking), and time since randomization, the analyses were adjusted for body-mass index (<23.01, >23.01 to 24.40, >24.40 to 26.40, or >26.40), frequency of vigorous physical activity (<1, 1 to 4, or >5 times per week), presence or absence of a family history of myocardial infarction, presence or absence of random assignment to aspirin use, and presence or absence of a history of hypertension, diabetes, and angina at enrollment. Four patients and two controls who were taking medication for high cholesterol levels were excluded. CI denotes confidence interval.

‡This group served as the reference group.
were higher among women who drank at least 7 g of alcohol per day than among those who drank less than 7 g per day of alcohol per day (Fig. 2B). Similar to the findings in the men, HDL levels among the women who drank at least 7 g of alcohol per day were highest among those who were homozygous for the $\gamma_1$ allele, intermediate among the heterozygotes, and lowest among those who were homozygous for the $\gamma_2$ allele ($P=0.02$ for the interaction).

**DISCUSSION**

We observed a strong interaction between the $ADH3$ genotype and the level of alcohol consumption in relation to the HDL level and the risk of myocardial infarction. Since the predominant function of alcohol dehydrogenase type 3 is to metabolize alcohol, this finding is consistent with the hypothesis that a slower rate of clearance of alcohol enhances the beneficial effect of moderate alcohol consumption on the risk of cardiovascular disease.

Approximately half the apparent benefit of alcohol consumption on the risk of myocardial infarction can be explained by an increase in the HDL level.6,21-23 We found that HDL levels were highest among men who consumed at least one drink per day in all three of the $ADH3$ genotype groups, but that the levels were
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highest among those who were homozygous for the \(\gamma_2\) allele. Our data suggest that the reduction in the risk of myocardial infarction attributed to the interaction between the \(ADH3\) genotype and the level of alcohol consumption is not due solely to an increase in the HDL level. However, we cannot accurately estimate how much of the modifying effect of the \(ADH3\) genotype on myocardial infarction is due to its effect on the HDL level, since there were only five patients who consumed at least one drink per day and who were homozygous for the \(\gamma_2\) allele.

Some have suggested that the inverse association between moderate alcohol intake and the risk of myocardial infarction does not represent a true causal relation, but rather that alcohol is a surrogate for favorable socioeconomic or lifestyle factors associated with a reduction in risk.\(^{24}\) It is unlikely that the \(ADH3\) genotype is associated with these potentially confounding factors, and we observed no such associations in our data. The finding of an effect of the functional \(ADH3\) polymorphism on the relations between moderate consumption of alcohol and the risk of myocardial infarction (and the HDL level) lends support to the plausibility of a causal interpretation. Associations observed in nonrandomized epidemiologic studies may be attributed to potentially confounding factors. Observed associations between the risk of a disease and the presence of functional variants in genes that lead to the metabolism or transduction of the factor that underlies the disease add substantial support to the idea that the exposure to the factor is directly related to causation.

Similarly, it has been proposed that the protective effect of the consumption of alcoholic beverages on heart disease may be due to constituents of alcoholic beverages other than ethanol (e.g., antioxidants such as flavonoids).\(^{35}\) The fact that alcohol dehydrogenase type 3 metabolizes ethanol, and not other compounds, suggests that ethanol is responsible for the protective effect. A key problem in environmental epidemiologic studies is that humans are exposed to complex mixtures of compounds, so identifying the specific beneficial or harmful compounds may not be possible. Improving our ability to identify specific lifestyle and environmental factors as causes of a given disease may prove to be one of the main benefits of the study of common variants in metabolic genes and disease.

The prospective design of our study, the relatively large number of newly diagnosed cases, and the high rate of completeness of follow-up data strengthen the validity of our results. Nonetheless, our study has potential limitations. Since alcohol intake was estimated on the basis of the subjects' responses to questionnaires, it may underestimate the true intake. Although the exact relation between self-reported intake and true intake is not known, similar questionnaires have been shown to provide useful estimates of alcohol intake over extended periods.\(^{26}\) Evidence suggests that the ranking of the intake of alcohol among the subjects from low to high in the Physicians' Health Study is quite accurate. Previous studies of this cohort have shown that the self-reported alcohol intake can be used to predict the risk of myocardial infarction,\(^{4}\) diabetes,\(^{27}\) stroke,\(^{28}\) and death from any cause.\(^{29}\) Such results are consistent with those of other studies that assessed alcohol intake in much greater detail. The correlation between HDL levels and alcohol intake in our group is consistent with the results of experimental studies of alcohol administration, and it thus supports the validity of the ranking of self-reported alcohol intake in this study population.

Another issue that needs to be addressed is the range of alcohol consumption over which the \(ADH3\) genotype influences the risk of myocardial infarction. Although we would not expect the \(ADH3\) genotype to have any effect on the risk of myocardial infarction among those who do not drink alcohol, we observed a nonsignificant reduction in risk among men who consumed little or no alcohol and who were homozygous for the \(\gamma_2\) allele. In addition, among men who consumed alcohol daily, there was no significant difference in the risk of myocardial infarction between heterozygotes and those who were homozygous for the \(\gamma_2\) allele despite the observed difference between these groups in HDL levels. This discrepancy could be attributed to the limited statistical power of the study, since confidence intervals in these subgroups were broad. Alternatively, some other mechanism may be at work.

Our study lacks the statistical power to determine the effect of the \(ADH3\) genotype on those who are heavy drinkers. Thus, our results are only generalizable to populations with light-to-moderate levels of alcohol consumption. Heavy consumption of alcohol is a risk factor for several diseases or conditions, such as alcoholism, stroke, and liver disease. Persons with a slow rate of metabolism of ethanol may have a reduced risk of coronary heart disease; however, they may be at higher risk for other alcohol-associated diseases. Studies among male and female populations with high levels of alcohol consumption are needed to assess this possibility.

In summary, we observed a marked and significant interaction between moderate alcohol consumption and the \(ADH3\) polymorphism. Men who drank daily and were homozygous for the \(\gamma_2\) allele had a substantially decreased risk of myocardial infarction — a decrease that was at least partially attributable to an increase in HDL levels.

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REFERENCES


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