Dietary Alcohol, Calcium, and Potassium
Independent and Combined Effects on Blood Pressure*

Michael H. Criqui, MD, MPH, Robert D. Langer, MD, and Dwayne M. Reed, MD, PhD

To determine whether or not the previously reported association between alcohol intake and high blood pressure is influenced by differential intake of calcium and potassium in drinkers compared with nondrinkers and to assess the magnitude of the independent contributions of alcohol, calcium, and potassium to blood pressure, these associations were evaluated in 7,011 men of Japanese descent. Categorical analyses and multiple linear regression techniques were used to test the hypotheses that alcohol, calcium, and potassium were independent predictors of blood pressure. Alcohol consumption above a threshold of approximately 20 ml/day was found to be positively, strongly, and independently correlated with systolic and diastolic pressures, and this effect was completely independent of the effects of calcium and potassium. Calcium and potassium intake were highly correlated (r=0.59) and were inversely related to blood pressure, and their combined effect was greater than the effect of either alone. However, in the subgroup of moderate and heavier drinkers, only potassium was inversely related to blood pressure. This finding is compatible with previous reports of malabsorption and increased excretion of calcium at higher levels of alcohol intake, and it indicates that a small portion of the alcohol-induced blood pressure elevation may be mediated through calcium depletion. In the range of dietary intake in this cohort, the effect of alcohol on blood pressure was stronger than was either the separate or combined effects of calcium and potassium. (Circulation 1989;80:609–614)

Although light consumption of alcohol has been linked to some reduction in coronary heart disease, heavier alcohol consumption is not protective and may actually increase risk.1 Heavier consumption has been shown to increase blood pressure,2–7 and such elevations have been directly linked to cardiovascular disease mortality.7 However, the mechanism of alcohol’s effect on blood pressure remains unclear. Postulated mechanisms include a withdrawal effect, a direct pressor effect, and reduced absorption of both vitamin D and calcium.7 The possibility that alcohol is a surrogate for differential dietary intake of important electrolytes that in turn leads to elevated blood pressure has received little attention.

Most of the research on nonalcohol dietary influence on blood pressure has focused on three electrolytes: sodium, potassium, and calcium.8–10 Recent evidence has encouraged some reassessment of the formerly secure position of sodium as the most important electrolyte in hypertension.9

Although the influence of potassium on blood pressure has not been investigated as thoroughly as that of sodium, it has been evaluated in some epidemiologic6,9,10 and experimental11,12 studies. Investigators in these studies have postulated that the inverse physiologic relations between potassium and sodium may explain the observed beneficial effect of potassium on blood pressure.

Calcium has received increasing attention as a potential modulator of blood pressure in the past 2 decades. Numerous epidemiologic studies,6,13–16 and some experimental trials17,18 have shown an inverse relation between dietary calcium and blood pressure. Although calcium has a role in several aspects of blood pressure regulation, a clear mechanism for its action on blood pressure has yet to be delineated.

We evaluated the independent and combined effects of calcium, potassium, and alcohol intake on blood pressure in a large cohort of men followed through the Honolulu Heart Program in an attempt to answer two major questions: Is the known rela-

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tion between alcohol intake and blood pressure confounded by differences in calcium or potassium intake in drinkers compared with nondrinkers? Do calcium and potassium have independent effects on blood pressure irrespective of the level of alcohol intake?

We did not evaluate sodium as a potential confounder because previous analyses in this population indicated sodium intake was not associated with blood pressure.\textsuperscript{5,6}

**Methods**

The Honolulu Heart Program is a prospective study of 8,006 men of Japanese descent born between 1900 and 1919 who were living on the island of Oahu in 1965. Details of the baseline examination, which included measurement of height, weight, and systolic and diastolic blood pressures, have been described previously.\textsuperscript{5,6} While the patient was sitting, blood pressures were measured twice by a nurse and once by a physician in the left arm with a mercury manometer (Baumanometer, WA Baum Copague, New York). The fifth Korotkoff phase was used for diastolic blood pressure. Blood pressure results were recorded as the mean of all three readings. Body mass index, a measure of obesity, was calculated as weight in kilograms divided by height in square meters.

Alcohol consumption was recorded as usual intake of beer, wine, and spirits for a 1-month period and converted as specified in the US Department of Agriculture (USDA) Handbook No. 8 (1963). This assessment correlates highly with previous day intake by 24-hour dietary recall ($r=0.68$). For convenience, we report alcohol consumption in milliliters per day.

Nutrient intake was estimated by a dietician using 24-hour recall methods\textsuperscript{19} that were validated against a 7-day diet record among 329 men in this same cohort.\textsuperscript{20} The results showed no significant difference between the two measures for 15 categories of nutrients, and day-to-day variability in this population was markedly less than usually observed in Western populations.\textsuperscript{20} The amount consumed of a particular nutrient was calculated by grouping foods into standard portions in 54 categories contained on the coding form. Nutrient values for the 54 categories were obtained with a computer program based on data contained in the USDA handbook and from a food table specifically constructed for this study. Nutrient values for items not listed on the coding form were hand calculated with the use of information from the USDA handbook.

Statistical analysis was performed with SAS computer software (SAS Institute, Cary, North Carolina). Correlation coefficients and partial correlation coefficients adjusted for age were calculated. The data were stratified by levels of alcohol, calcium, and potassium intake, with age adjustment by the SAS GLM procedure. Multivariate analysis was performed with SAS-multiple linear regression, and product interaction terms between each of the nutrients of interest were explored. Body mass index was included as a potential confounder in multivariate analysis. Socioeconomic status was not included because previous analyses in this population showed no association between blood pressure and education or father's occupation.\textsuperscript{5}

**Results**

Data from 7,011 subjects not on antihypertensive therapy and for whom information was available on alcohol consumption, calcium intake, potassium intake, and blood pressure were used in this analysis. Figure 1 shows the age-adjusted association of alcohol, in 10-ml increments, with systolic and diastolic blood pressures. The increase in blood pressure began at about 20 ml/day, with no clear association at lower levels of alcohol. Because of this finding, for analyses of electrolyte effects within each alcohol category, the population was divided into three groups of roughly equal size: nondrinkers ($n=2,553$), light drinkers ($<13.3 \text{ ml/day}, n=2,131$), and moderate and heavier (“moderate plus”) drinkers ($>13.3 \text{ ml/day}, n=2,327$). The median intake in all drinkers was 13.3 ml/day.

Table 1 shows the age-adjusted associations of calcium and potassium intake, dichotomized at less than or greater than the mean, with systolic and
TABLE 1. Age-Adjusted Systolic and Diastolic Blood Pressures by Levels of Alcohol, Calcium, and Potassium Intake

<table>
<thead>
<tr>
<th>Intake (mg)</th>
<th>Ca²⁺</th>
<th>K⁺</th>
<th>SBP</th>
<th>DBP</th>
<th>SBP</th>
<th>DBP</th>
<th>SBP</th>
<th>DBP</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (265)</td>
<td>Low</td>
<td>133.2</td>
<td>81.6</td>
<td>133.2</td>
<td>82.2</td>
<td>135.6</td>
<td>82.8</td>
<td></td>
<td>(2,489)</td>
</tr>
<tr>
<td>High (326)</td>
<td>Low</td>
<td>133.9</td>
<td>81.5</td>
<td>131.8</td>
<td>81.9</td>
<td>134.8</td>
<td>83.1</td>
<td></td>
<td>(1,021)</td>
</tr>
<tr>
<td>Low (591)</td>
<td>High</td>
<td>131.5</td>
<td>80.4</td>
<td>130.4</td>
<td>81.3</td>
<td>136.7</td>
<td>82.4</td>
<td></td>
<td>(1,017)</td>
</tr>
<tr>
<td>High (777)</td>
<td>High</td>
<td>129.1</td>
<td>79.9</td>
<td>129.7</td>
<td>80.6</td>
<td>132.6</td>
<td>81.4</td>
<td></td>
<td>(2,484)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>135.6</td>
<td>82.8</td>
<td>134.8</td>
<td>83.1</td>
<td>136.7</td>
<td>82.4</td>
<td></td>
<td>(7,011)</td>
</tr>
</tbody>
</table>

SBP, systolic blood pressure (mm Hg); DBP, diastolic blood pressure (mm Hg).

diastolic blood pressures at three levels of alcohol consumption. Because of the positive correlation between calcium and potassium, the concordant groups (low-low and high-high) had more than twice as many subjects as the discordant groups (low-high and high-low). Within each category of calcium and potassium combined intake, systolic and diastolic blood pressures were similar in nondrinkers and light drinkers but higher in moderate plus drinkers, indicating an independent effect of alcohol. In nondrinkers and light drinkers, higher levels of calcium and potassium appeared to be associated with lower blood pressure, with an additive effect when both calcium and potassium were high. However, only potassium appeared to be associated with lower systolic blood pressure in moderate plus drinkers.

The data in Table 1 involve a rather simple cross classification, and in fact, calcium intake was predictably lower in the low-low group (265 mg/day) than in the low-high group (326 mg/day), and potassium was lower in the low-low group (1,448 mg/day) than in the high-low group (1,695 mg/day). In addition, the data were not adjusted for an important confounder, body mass index.

For these reasons, multiple linear regression was performed on the data from moderate plus drinkers (the only group in which an alcohol-blood pressure effect was seen) (Table 2). In these models, the coefficients represent units of 10 ml/day for alcohol and 100 mg/day for calcium and potassium. The alcohol coefficient was unchanged, whether or not calcium and potassium were included in the model. Additional models with interaction terms for the products of each of the dietary variables revealed no significant interactions. In these models, potassium was significantly inversely associated with both systolic (p<0.0001) and diastolic blood pressures (p<0.016), whereas calcium was not (p=0.10 for systolic and p=0.78 for diastolic blood pressure).

Table 3 shows the results of multiple linear regression in nondrinkers and light drinkers. These groups were combined for analyses because separate multivariate analyses of these groups showed very similar results. Because calcium and potassium were highly correlated, r=0.59, multivariate analyses were performed initially with either calcium or potassium in the model and then with both. Calcium and potassium were inversely related to systolic and diastolic blood pressures. However, the results for systolic were stronger than for diastolic blood pressure. When calcium and potassium were included in the model, they were of roughly equal weight, but their effect was not quite significant. As an example, for systolic blood pressure, the calcium coefficient was -0.212, p=0.051, whereas the potassium coefficient was -0.079, p=0.16. The high intercorrelation of these two electrolytes might have influenced these results.6 In these two groups, as

### Table 2. Multiple Linear Regression Coefficients in Moderate Plus Drinkers

<table>
<thead>
<tr>
<th></th>
<th>Systolic blood pressure</th>
<th>Diastolic blood pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alcohol</td>
<td>Ca²⁺</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age+BMI</td>
<td>0.920†</td>
<td>—</td>
</tr>
<tr>
<td>+ alcohol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age+BMI</td>
<td>0.918†</td>
<td>0.185</td>
</tr>
<tr>
<td>+ alcohol+Ca²⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age+BMI</td>
<td>0.945†</td>
<td>0.307</td>
</tr>
<tr>
<td>+ alcohol+Ca²⁺+K⁺</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=2,325 subjects.
BMI, body mass index.
*p<0.016; †p<0.0001.
predicted by Figure 1, alcohol was not significantly related to systolic or diastolic blood pressure. Although the alcohol coefficients were large, the standard errors were much greater than in the moderate plus drinkers.

In all the models in Tables 2 and 3, body mass index was a strong and significant predictor of systolic and diastolic blood pressures. Age was a strong and significant predictor of systolic blood pressure in all models but less predictive for diastolic blood pressure. Additional models were run with calcium and potassium intake per 1,000 kcal as independent variables. The results were unchanged, so only the first set of models are presented.

To evaluate the independent change in blood pressure caused by each of the three dietary factors, selected ranges of intake were chosen (Table 4). The range evaluated for alcohol was that between nondrinkers (0) and the mean of the heavier drinkers, about 40 ml/day. For calcium, the range was between the means of the lowest group (low-low) and the highest group (high-high), about 500 mg/day. For potassium, the range was also between the means of the low-low and high-high groups, about 1,500 mg/day. These ranges reflect intuitively comprehensible behavioral differences rather than standard deviations. The β coefficient chosen for alcohol was from Table 2 (moderate plus drinkers, the only group with an effect), for calcium from Table 3 (the nondrinkers and light drinkers, no effect was present in moderate plus drinkers), and for potassium from an average across all three groups (because an effect was present in each group). In this analysis, alcohol’s positive effect on both systolic and diastolic blood pressures was greater than either the separate or combined effects of calcium and potassium.

Discussion

These findings confirm that alcohol, along with body mass index and age, are strong predictors of systolic blood pressure. Alcohol and body mass index are strong predictors of diastolic blood pressure. This is consistent with other reports. In addition, a threshold effect of alcohol at about 20 ml (Figure 1), or 1–1.5 drinks/day, has been suggested by several, but not all, other studies. This evidence has recently been reviewed. The present analysis thus confirms earlier work on dietary correlates of blood pressure in this cohort, but in addition, it adds important new information concerning the differential effects of these nutrients at different levels of alcohol intake. Calcium was associated with blood pressure only at absent-to-light levels of alcohol intake. Potassium, however, was inversely associated with blood pressure irrespective of alcohol intake and in fact had a stronger protective effect in moderate plus drinkers. In comparing the effects of these three nutrients, the data in Table 4 indicate that variability in alcohol intake in this population is a more important predictor of blood pressure than is either calcium or potassium. A previous report on blood pressure from the Netherlands showed a positive association for alcohol and inverse associations for calcium and potassium, but that report did not stratify by the level of alcohol intake.

Because alcohol affected blood pressure only in moderate plus drinkers, analysis of the potential confounding effect of calcium and potassium on this association was restricted to this group. The data in Table 2 indicate complete independence of the alcohol–blood pressure associations from calcium and potassium. In fact, there was little potential for

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**TABLE 3. Multiple Linear Regression Coefficients in Nondrinkers and Light Drinkers Combined**

<table>
<thead>
<tr>
<th></th>
<th>Systolic blood pressure</th>
<th>Diastolic blood pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alcohol</td>
<td>Ca(^{2+})</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age+BMI+Alcohol</td>
<td>0.548</td>
<td>—</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td>—</td>
</tr>
<tr>
<td>Age+BMI+Alcohol+Ca(^{2+})</td>
<td>0.414</td>
<td>—0.303†</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age+BMI+Alcohol+K(^+)</td>
<td>0.500</td>
<td>—</td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td>—0.212</td>
</tr>
</tbody>
</table>

\(n = 4,679\) subjects. 
BMI, body mass index. 
\(^t p < 0.03; \; \; t p \leq 0.01.\)

**TABLE 4. Effect of Selected Ranges of Dietary Alcohol, Ca\(^{2+}\), and K\(^+\) on Systolic and Diastolic Blood Pressures**

<table>
<thead>
<tr>
<th></th>
<th>△ Systolic blood pressure (mm Hg)</th>
<th>△ Diastolic blood pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(40 ml/day △)</td>
<td>+3.7</td>
<td>+1.4</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(500 mg/day △)</td>
<td>−1.1</td>
<td>−0.3</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1,500 mg/day △)</td>
<td>−2.0</td>
<td>−0.7</td>
</tr>
</tbody>
</table>
confounding because within the moderate plus alcohol group simple age-adjusted correlations between alcohol and these two electrolytes were weak and not statistically significant. This is in sharp contrast to the calcium-alcohol correlation for the entire cohort, which was inverse and highly significant. The potassium-alcohol correlation was not significant in the entire cohort.

In the multiple linear regression for moderate plus drinkers (Table 2), the calcium coefficient was nonsignificant and curiously positive in sign. This latter result may reflect the previously reported malabsorption\textsuperscript{24} or increased excretion\textsuperscript{25} of calcium with alcohol consumption. Thus, even though not confounded in the formal statistical sense, one interpretation of these results is that alcohol has part of its biologic effect on blood pressure by preventing the action of calcium. However, the calculated values in Table 4 suggest that, even making the extreme assumption that ethanol could completely prevent the hypotensive effect of calcium, this pathway would still only explain a small portion of alcohol’s effect.

We were not able to analyze magnesium intake in this study because magnesium intake data were only available on a small subset of this cohort. However, in that small subset, magnesium intake was highly correlated with calcium and potassium intake, and it was inversely related to blood pressure.\textsuperscript{26} Because alcohol causes a marked excretion of magnesium (in addition to calcium),\textsuperscript{25} alcohol may interfere with the hypotensive effect of magnesium as well as of calcium.

Both calcium and potassium were protective against elevations in blood pressure in nondrinkers and light drinkers, and their combined effect was greater than either of their individual effects. Milligram for milligram, calcium had a somewhat greater effect (Table 3), but the intakes of potassium were higher (Table 1). Roughly speaking, average variations in potassium intake were associated with the same blood pressure differences as average variations in calcium intake, except in the moderate plus drinkers, when only potassium appeared to have an effect.

The strong correlation between potassium and calcium ($r=0.59$) and the consistently greater effect of the two combined compared with either one alone raises the possibility that some multicollinearity in these models may have limited our ability to assess confounding.\textsuperscript{6} For this reason, multivariate analyses in nondrinkers and light drinkers were performed initially with only one electrolyte in the model.

Only potassium was inversely related to blood pressure in moderate plus drinkers. It is unclear why potassium coefficients were greater in moderate plus drinkers than in nondrinkers and light drinkers. A possible explanation has been shown in human metabolic studies in which potassium excretion was decreased with ethanol administration.\textsuperscript{25} This finding is compatible with a relatively greater effect of potassium in drinkers compared with nondrinkers.

The alcohol–blood pressure link is now a well-established finding.\textsuperscript{2-7} However, the independence of the alcohol effect from dietary calcium and potassium, the lack of calcium effect with increasing alcohol intake, and the importance of potassium intake as an independent and inverse predictor of blood pressure with increasing alcohol intake, have not, to our knowledge, previously been reported.

We have considered potential limitations of our data. First, the subjects included in this study were not necessarily representative of the US population at large; they were all men, of Japanese ancestry, born between the years of 1900 and 1919, and they were living on the island of Oahu at the time these data were collected. Therefore, generalizability of these findings cannot be certain. Second, considerable misclassification bias may enter into an analysis based on 24-hour dietary recall. Nevertheless, as discussed above, the instrument used in this study has been validated against the more exacting 7-day diet log technique.\textsuperscript{19,20} Misclassification bias in the dietary data would likely be conservative and thus tend to obscure true associations.\textsuperscript{27}

In summary, we have shown a strong, consistent, and independent positive association between alcohol intake and systolic and diastolic blood pressures that was not confounded by either calcium or potassium intake. Potassium intake and calcium intake were highly correlated. A protective effect was present for potassium consumption on blood pressure irrespective of alcohol intake. However, the inverse relation between calcium intake and blood pressure was not seen in moderate plus drinkers, a finding compatible with the known malabsorption and increased excretion of calcium at higher levels of alcohol consumption.

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