RESEARCH REPORT

Geochemistry of ground water and the incidence of acute myocardial infarction in Finland

A Kousa, E Moltchanova, M Viik-Kajander, M Rytkönen, J Tuomilehto, T Tarvainen, M Karvonen, for the Spat Study Group

Study objective: To examine the association of spatial variation in acute myocardial infarction (AMI) incidence and its putative environmental determinants in ground water such as total water hardness, the concentration of calcium, magnesium, fluoride, iron, copper, zinc, nitrate, and aluminium.

METHODS

Finnish ground water is slightly acidic and very soft (1–4˚dH) or soft (4–8˚dH). Besides the geological factors affecting trace element composition, atmospheric, anthropogenic, and marine factors also contribute to the chemical composition of the ground water.21

The data on men aged 35–74 years with the first attack of AMI (18946 cases) were obtained from the nationwide Death Register and the Hospital Discharge Register. The national personal identification number was used to perform a computerised records linkage of the data for deaths and hospitalisation attributable to AMI (ICD-8 and ICD-9 codes 410–414). Both fatal and non-fatal events from the years 1983, 1988, and 1993 were included in the study. Cases with a previous hospitalisation for AMI were excluded. Data for these three years have been pooled. The data on population at risk, provided by coordinates of the place of residence, were obtained from Statistics Finland. The data were aggregated into 10 km x 10 km grid cells to ensure the protection of privacy of the individuals.

Geochemical data were obtained from the hydrogeochemical database of the Geological Survey of Finland.22 The data on total water hardness (˚dH), Ca, Mg, Fe, F–, NO3– (mg/l) and Cu, Zn, and Al (µg/l) were available. Element concentrations were determined with different methods, for example, ICP-MS, ICP-AES, iconography, and AAS. The original data contained from 3621 up to 12 407 ground water samples.

The geochemical data were interpolated into a regular grid by using the ALKEMIA software developed at Geological Survey of Finland.23 In the ALKEMIA Smooth interpolation method, the nearest samples to the grid cell receive greater

Abbreviations: CVD, cardiovascular disease; AMI, acute myocardial infarction; CHD, coronary heart disease
Geochemistry and acute myocardial infarction

137

weight. The value of the cell is a weighted median of sample values.25–26

Bayesian spatial conditional autoregressive model (CAR) with covariates, which is currently in wide use in the field of the disease mapping, was applied in this study.27–30 Because Finland is sparsely inhabited, we propose one modification, which is pertinent to the sparsely populated areas. In the case of the 10 km x 10 km grid over Finland (excluding Lapland), some grid cells are empty and have to be omitted from the analysis; thus 5% of cells would be omitted. However, once we take environmental factors into account, assuming that the disease risk is influenced by both demographic factors (that is, people who actually live within the grid cell) and environmental factors in each cell whether or not it is inhabited, the omission of unpopulated cells results in a loss of information. The covariates included in the model were the age of onset of AMI and the levels of geochemical compounds in the ground water. The following modification is thus proposed.

Let Y* denote the number of cases in the cell i and age group k. Furthermore, let N* denote the respective population at risk. The proposed probability distribution is then as follows:

\[ P(Y_i = y | N_i, \mu_i) = \begin{cases} \frac{e^{-\mu_i} (\mu_i^y)}{y!} & \text{if } 0 \leq y \leq N_i \\ 0 & \text{elsewhere} \end{cases} \]

that is, the Poisson distribution is assigned to the inhabited cells and the uninhabited cells naturally have no cases of the disease with the unit probability. Also we assign common regression structure to the \( \mu_i \):

\[ \log(\mu_i) = \alpha + \lambda_i + \beta_k + \xi_i + \log(N_i) \]

if \( N_i > 0 \)

\[ \log(\mu_i) = \alpha + \lambda_i + \beta_k + \xi_i \]

if \( N_i = 0 \)

where

\( \alpha \) is the baseline risk

\( \lambda_i \) is the local unexplained spatial random effect

\( \beta_k \) is the effect of age group k on the risk level

\( K \) is the age group, \( k = 0, \ldots, K \)

\( \xi_i \) is a vector of environmental covariate effects

\( Z_i \) is a vector of environmental covariates for area i

In this analysis, the age axis was divided into eight, five year age groups: 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, and 70–74. A non-proportional hazard model described their effect, which for AMI is more appropriate for the spatial variation of the incidence of AMI.

DISCUSSION

The large geographical variation and changes in the incidence of AMI in Finland cannot be explained by individual lifestyle or genetic factors alone; environmental exposures must also contribute to the development of the disease. The classic risk factors and socioeconomic status provide only a partial explanation for the excess CHD risk in eastern Finland.31 The population distribution did not have an effect on the geographical variation of the incidence of AMI. The results support the early observations of the inverse relation between the AMI incidence and total water hardness. An

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Geochemical concentrations in ground water in Finland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
<td>Median</td>
</tr>
<tr>
<td>Water hardness (°dH)</td>
<td>2.8</td>
</tr>
<tr>
<td>Ca (mg/l)</td>
<td>14.4</td>
</tr>
<tr>
<td>Mg (mg/l)</td>
<td>3.3</td>
</tr>
<tr>
<td>Zn (µg/l)</td>
<td>11.4</td>
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<tr>
<td>Al (µg/l)</td>
<td>10.4</td>
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<tr>
<td>Cu ( µg/l)</td>
<td>2.4</td>
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<tr>
<td>F (mg/l)</td>
<td>0.1</td>
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<tr>
<td>Fe (mg/l)</td>
<td>0.0</td>
</tr>
<tr>
<td>NO3- (mg/l)</td>
<td>1.0</td>
</tr>
</tbody>
</table>
inverse relation between water hardness and CVD mortality has been detected in several studies. They have suggested that CHD mortality can be related to the amount of magnesium and calcium in drinking water. In some studies an association between CVD and water hardness was not found. Much of the disagreement in earlier studies may be related to the complexity of the ecological analysis and the difficulty to apply results from ecological studies at the individual level. In the general population, the magnesium intake has decreased over the years especially in the western world. Some previous studies have shown that a large number of subjects had a lower intake of magnesium than the recommended dietary amount (350 mg/day). It has been suggested that magnesium in water, as hydrating ions, has a higher bioavailability than magnesium in food, which is bound in different compounds that are less easily absorbed.

Fluoride concentrations of around one mg/l in household water may be beneficial. Recent studies have also provided evidence that high serum iron and copper concentrations are associated with the CHD. In this study one mg/l increment in the fluoride concentration in the drinking water was associated with a 3% decrease in the risk of AMI. In our study one µg/l increment in copper and one mg/l increment in iron on average increased the risk of AMI by 4% and 10%, respectively. The differences were not, however, statistically significant. The non-significant results in our study may be attributable to excessive smoothing technique. Thus, our study provides further supportive evidence for the importance of the ground water fluoride, iron and, copper concentrations for the risk of AMI.

CHD has a multifactorial aetiology. The method of spatial analysis used in this study is especially useful for testing the impact of several factors simultaneously. The validity of the Bayesian method used in this study has been also demonstrated earlier studies. Additional simulations have been run to check the validity of the proposed changes to it regarding the inclusion of the uninhabited cells in the analysis.

Ground water reflects the contents of trace elements in soil and bedrock but only a small proportion of the population use locally produced food supplies, cereals, and vegetables. Individual studies on the role of intake of both food and water-borne nutrients should incorporate environmental exposure or control for it.

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