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LEAD CONCENTRATIONS IN DRINKING WATER IN EUROPE AND CARDIOVASCULAR MORTALITY

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Abstract

Epidemiological observations concerning the relationship between water hardness, concentrations of lead (Pb) in drinking water, and cardiovascular mortality in Great Britain and Norway suggest that Pb may have been far more important than hitherto recognized as one of the main causes of the 20th Century coronary heart disease epidemic in the United States and Europe.

The aim of this study was a literature review of the association between Pb concentrations in the environment, in blood, and cardiovascular diseases.

Materials and Methods. The search for relevant scientific publications was carried out in databases of evidence-based medicine (PubMed, Cochrane Library), and specialized search systems (Google Scholar). The following search filters or inclusion criteria were used: environmental studies on Pb sources in the environment, drinking water and food, epidemiological studies on the association between Pb and cardiovascular pathology, on the hardness of drinking water, published in English, full versions of articles. Preference was given to studies of high methodological quality (cohort studies and reviews of studies of various designs), in the absence of which results of cross-sectional studies were taken into account.

The research was obtained by searching the following keywords: drinking water AND lead; cardiovascular diseases AND lead; mortality AND lead.

Results. It was found a correlation between blood Pb concentration and both systolic and diastolic blood pressure, stroke, and heart attacks. The toxic effects of Pb can explain the association between water hardness and cardiovascular mortality.

Key words: *drinking water; lead; cardiovascular disease; mortality.*

Резюме

КОНЦЕНТРАЦИЯ СВИНЦА В ПИТЬЕВОЙ ВОДЕ В ЕВРОПЕ И СМЕРТНОСТЬ ОТ СЕРДЕЧНО-СОСУДИСТЫХ ЗАБОЛЕВАНИЙ

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Эпидемиологические наблюдения, касающиеся взаимосвязей между жесткостью воды, концентрациями свинца в питьевой воде (Pb) и смертностью от сердечно-сосудистых заболеваний в Великобритании и Норвегии, позволяют предположить, что свинец, возможно, играет гораздо более важную роль в развитии эпидемии ишемической болезни сердца в США и Европе 20-го века, чем это до сих пор признавалась.

Целью данного исследования был обзор литературы о связи содержания свинца в окружающей среде и крови с сердечно-сосудистыми заболеваниями.

Материалы и методы. Поиск соответствующих научных публикаций проводился в базах данных доказательной медицины (PubMed, CochraneLibrary), специализированных поисковых системах (GoogleScholar). Использовались следующие поисковые фильтры или критерии включения: экологические исследования источников свинца в окружающей среде, питьевой воде и продуктах питания, эпидемиологические исследования взаимосвязи патологии свинца и сердечно-сосудистой системы, жесткости питьевой воды, опубликованные на английском языке, полные версии статей. Предпочтение было отдано исследованиям высокого методологического качества (когортные исследования и обзоры исследований различного дизайна), при отсутствии которых учитывались результаты поперечных исследований.

Исследование было получено путем поиска следующих ключевых слов: питьевая вода и свинец; сердечно-сосудистые заболевания и свинец; смертность и свинец.

Результаты. Была обнаружена корреляция между концентрацией свинца в крови и систолическим и диастолическим артериальным давлением, инсультом и инфарктом. Токсические эффекты Pb могут объяснить связь между жесткостью воды и сердечно-сосудистой смертностью.

Ключевые слова: *питьевая вода; свинец; сердечно-сосудистые заболевания; смертность.*

Түйіндеме

ЕУРОПАДАҒЫ АУЫЗ СУДАҒЫ ҚОРҒАСЫННЫҢ ШОҒЫРЛАНУЫ ЖӘНЕ ЖҮРЕК-ҚАН ТАМЫРЛАРЫ АУРУЛАРЫНАН БОЛАТЫН ӨЛІМ-ЖІТІМ

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Судың қатаңдығы, ауыз судағы қорғасынның концентрациясы (Pb) және Ұлыбритания мен Норвегиядағы жүрек-қан тамырлары ауруларынан болатын өлім арасындағы өзара байланыстарға қатысты эпидемиологиялық бақылау қорғасын осы күнге дейін танылғанға қарағанда, АҚШ пен 20-шы ғасырдың Еуропада жүректің ишемиялық ауруы індетінің дамуында анағұрлым маңызды рөл атқарады деп болжауға мүмкіндік береді.

Зерттеудің мақсаты қоршаған ортадағы қорғасын мен қан құрамының жүрек-қан тамырлары ауруларымен байланысы туралы әдебиеттерді шолу болды.

Материалдар мен әдістер. Тиісті ғылыми басылымдарды іздестіру дәлелді медицинаның деректер базасында (PubMed, CochraneLibrary), мамандандырылған іздеу жүйелерінде (GoogleScholar) жүргізілді. Келесі іздеу сүзгілері немесе қосу өлшемдері пайдаланылды: қоршаған ортадағы, ауыз судағы және азық-түлік өнімдеріндегі қорғасын көздерінің экологиялық зерттеулері, қорғасын патологиясы мен жүрек-қантамыр жүйесінің өзара байланысын, ауыз судың ағылшын тілінде жарияланған қаттылығын, мақалалардың толық нұсқаларын эпидемиологиялық зерттеу. Артықшылық жоғары әдіснамалық сападағы зерттеулерге (когорттық зерттеулер және әртүрлі дизайн зерттеулерінің шолулары) берілді, олар болмаған жағдайда көлденең зерттеулердің нәтижелері ескерілді.

Зерттеу келесі негізгі сөздерді іздеу арқылы алынды: ауыз су және қорғасын; жүрек-тамыр аурулары және қорғасын; өлім және қорғасын.

Нәтижелер. Қандағы қорғасын концентрациясы мен систолалық және диастолалық артериялық қысым, инсульт және инфаркт арасындағы корреляция анықталды. Pb уытты әсерлері судың қатаңдығы мен жүрек-тамыр өлімінің арасындағы байланысты түсіндіре алады.

Түйінді сөздер: *ауыз су; қорғасын; жүрек-тамыр аурулары; өлім.*

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Introduction

Water used for irrigation may be a potential source of lead (Pb) to the soil [1-3]. A study of water and crops showed that the concentration of Pb, cadmium (Cd), and other metals in sewage-contaminated water was up to 210 times higher than in shallow handpump water [4]. Since clean water (and soil) is not easily accessible to the population of all countries, assuring safe (uncontaminated) water supplies is a pressing issue of great public health importance. This is demonstrated by an animal study. Shed skins from cobras and wall lizards collected from heavily polluted urban areas frequently contain significantly higher Pb levels than those of the same animals from less polluted rural areas [5].

Drinking water can be an important source of Pb, partly because of the possibility of much better intestinal absorption than for much of the Pb coming from other foods, with dietary calcium (Ca) and phosphorus (P), and perhaps also other substances in food being important factors that limit the intestinal absorption of Pb [6-13], while Pb from tapwater alone or when used for reconstitution of commercial infant foods can be much better absorbed [14, 15]. Ingestion of Pb from drinking water used to be a severe problem in many British cities for more than two decades into the post-World War 2 period because of the high prevalence of houses with Pb service pipes, the low pH of the public water supply and the resulting high levels of Pb in water used for public consumption [16, 17].

The aim of this study was a literature review of the association between Pb content in the environment and blood and cardiovascular diseases.

Materials and Methods

The search for relevant scientific publications was carried out in databases of evidence-based medicine (PubMed, Cochrane Library), and specialized search systems (Google Scholar). The following search filters or inclusion criteria were used: environmental studies on Pb sources in the environment, drinking water and food, epidemiological studies on the association between Pb and cardiovascular pathology, on the hardness of drinking water, published in English, full versions of articles. Preference was given to studies of high methodological quality (cohort studies and reviews of studies of various designs), in the absence of which results of cross-sectional studies were taken into account.

The research was obtained by searching the following keywords: drinking water AND lead; cardiovascular diseases AND lead; mortality AND lead.

A total of 753 literary sources were found, of which 50 articles were selected for subsequent analysis.

Results and discussion

An investigation from Ayr City in the southwest of the coast in Scotland illustrates the great importance Pb in drinking water can have for the total Pb burden in human populations [18]. The local water supply was plumbosolvent, and many dwellings in Ayr contained Pb pipes. In 1981, treatment of the water supply to reduce its plumbosolvency was initiated. Measurements of water and blood Pb concentrations were made before and after the treatment [18]. Most of the measurements carried out before and after water treatment began were made on water samples from the same dwellings and blood samples from the same women. Water treatment was fund to produce a sharp fall in water Pb concentrations and a decrease in the median blood Pb concentration from 21 to 13 micrograms/100 ml [18]. Two women had higher than expected blood Pb levels. Both of these women had been removing old paint. All of the women who had Pb pipes removed from their dwellings showed substantial decreases in their blood Pb concentrations [18].

The relationship between Pb intake from the diet and drinking water and the Pb concentration in the blood were also studied [19]. A cube root relationship was found to fit the data on blood Pb versus water Pb better than a linear relationship [19]. Similarly, blood Pb was also found to vary with the cube root of weekly dietary Pb intake. These cube root equations provided a means of estimating the impact on blood Pb concentrations of exposure to Pb from food and water. If the cube root relationships did correctly describe the association between these parameters, then the curve fitted to the results for adults indicating that the contribution to the blood Pb concentrations from sources other than the diet and water was relatively small [19]. A similar cube root relationship was also found between drinking water Pb concentration and Pb concentrations in blood from infants. However, the effect of Pb from drinking water on Pb concentrations in blood was found to be considerably smaller among wholly breastfed infants than on the others [20]. The same cube-root relationship has also been found between domestic water Pb concentrations and blood Pb concentrations in 232 mothers at delivery [21].

A survey of middle-aged men in 24 British towns showed that there was substantial geographical variation in blood Pb concentrations [22]. Cities with the highest mean blood Pb levels had soft water supplies. It was found that raised household tap water Pb concentrations could considerably increase individual blood Pb. Mean blood Pb was estimated to be 43% higher for men when the concentration of Pb in first-draw domestic tap water was 100 micrograms/l compared with a zero level [22]. Individual blood Pb was, however, also found t be affected by alcohol consumption and cigarette smoking, such that on average, these two lifestyle habits together contribute an estimated 17% to the blood concentration of Pb in middle-aged men [22].

While Pb pipes were used for drinking water supply by the ancient Romans, and perhaps have been used in several countries during the XIX Century, this practice did at least not continue in other countries for such a long period as it did in Great Britain, although Pb pipes may have survived in many old buildings. However, Pb may still have entered the drinking water from other sources than the pipes themselves, *viz.* from solder metal (lead-tin alloys) used for joining the pipes and from brass used in water taps that had been alloyed with Pb to improve its technical properties during the process of manufacture [23-28].

A study of heavy metal concentrations in the drinking water of randomly samples households in Oslo was carried out after Cd poisoning of drinking water had been discovered in a new building for the Institute of Biology at the University of Oslo. Some aquatic organisms that were used in laboratory experiments became poisoned, and when the researchers tried to find out what had happened, it was found that the taps in the new building had been plated with Cd. This alerted the public health authorities and prompted an investigation to try to measure the prevalence of Cd-poisoned drinking water among households in Oslo. This study showed that Cd poisoning of drinking water was rare, while high levels of Pb were very common, though not equally high, as in British cities with plumbosolvent water. One of the most important sources of the drinking water Pb was found to be water taps made from Pb-alloyed brass [29].

A strong inverse relationship has been found between drinking water hardness (defined as the sum of Ca^{++} and Mg^{++} concentrations in drinking water) and cardiovascular mortality in British cities [30]. In a study of regional variations in cardiovascular mortality in Great Britain during 1969-73 based on 253 towns, the possible contributions of drinking water quality, climate, air pollution, blood groups, and socioeconomic factors were evaluated [30]. A twofold range in mortality from stroke and ischaemic heart disease was apparent, with the highest mortality being in the west of Scotland and the lowest in South East England [30]. A multifactorial approach was found to identify five principal factors that substantially explained this geographic variation in cardiovascular mortality-namely, water hardness, rainfall, temperature, and two social factors (percentage of manual workers and car ownership). After adjustment for other factors cardiovascular mortality in areas with very soft water, around 0.25 mmol/l ($CaCO_3$ equivalent 25 mg/l), was estimated to be 10-15% higher than that in areas with medium-hard water, around 1.7 mmol/l (170 mg/l), while any further increase in hardness beyond 1.7 mmol/l did not additionally lower cardiovascular mortality [30]. Thus, a negative relationship existed between water hardness and cardiovascular mortality, although climate and socioeconomic conditions also appeared to be important influences.

Later, the association between blood Pb concentration, blood pressure, stroke, and heart attacks in middle-aged British men was similarly studied [31]. The relationship between blood Pb concentration and blood pressure was examined in a survey of 7371 men aged 40 to 59 from 24 British towns. It was found that after allowance for relevant confounding variables, including the city of residence and alcohol consumption, there existed a very weak but statistically significant positive association between blood Pb and both systolic and diastolic blood pressure. These cross-sectional data indicated that an estimated mean increase of 1.45 mm Hg in systolic blood pressure occurs for every doubling of blood Pb concentration with a 95% confidence interval of 0.47 to 2.43 mm Hg. After six years of follow-up, 316 of these men had major ischemic heart disease, and 66 had a stroke. After allowance for the confounding effects of cigarette smoking and town of residence, there was no evidence that blood Pb is a risk factor for these cardiovascular events. However, as the blood Pb-blood pressure association was so weak, it was considered unlikely that any consequent association between Pb and cardiovascular disease could be demonstrated from prospective epidemiological studies [31].

In some studies, it was found that the level of lead in bone tissue is a more accurate biomarker of its cumulative effect than Pb concentration in the blood. So, in a sample of 868 men, a correlation between the lead content in the patella, all-cause mortality, and cardiovascular mortality was found. The adjusted relative risks were 2.52 (DI 95%, 1.17–5.41) and 5.63 (DI 95%, 1.73–18.3), respectively. Approximately the same results were found when analyzing the content of lead in the tibia [32].

A criticism that can be raised against both of these studies, not against the statistical data that has been used, but against their interpretation, is that it is a wholly open question if the correlations observed between climatic factors (rainfall and temperature) and cardiovascular mortality in a medical sense are causal ones, or if they just might be confounding factors that erroneously have been interpreted as being causal because there is a strong correlation between climate and topography and drinking water corrosive properties, in addition to the obvious effect of bedrock composition on the composition of drinking water.

However, bedrock composition on the British Isles is also strongly correlated with climate, going from the Southeast of England to the North of Scotland, since limestones are much more abundant in South East England than in Scotland [33]. Most of Scotland belongs in a geological sense to the Caledonides, which are also found on the west side of the Scandinavian Peninsula and the east coast of Greenland, and the bedrock composition in Scotland is entirely dominated by silicate rocks, both metamorphic and igneous ones. In Scotland, moreover, the combination of climate, bedrock composition, and topography is also favorable to vegetation types (including mountain bogs and heather-covered terrain), giving acid soils with high concentrations of organic matter, similarly as on the west coast and most of the northern part of Norway. The average contribution of surface runoff, compared to groundwater discharge, into brooks, rivers, and lakes are also high in much of Scotland because of the combination of topography and climate. This, however, does not mean that the climate today determines what type of sediments were deposited either in what is now Norway or in what is now Scotland more than 65 million years ago or what happened during the Caledonian orogeny much earlier. Nor does it mean that the bedrock composition has any effect on climate either on the British Isles or in Norway today except an indirect one (which, however, is quite large) because of its effect on local topography [34].

It is thus possible that the real (casual) contribution to cardiovascular death rates in the study of Pocock et al. from 1980 may have been much more than 10-15 % variation if one corrects for over-correction of the data by falsely assuming confounding factors to be causal.

A similar inverse relationship, but much weaker than in Great Britain, between drinking water hardness and cardiac mortality, has also been observed in other countries, including the United States [35-38]. It has very commonly been speculated that it might be the magnesium (Mg) content of hard drinking water that might be the causal factor explaining this statistical relationship since it has been well-known for several years that Mg deficiency is harmful to the heart. Prompted by these speculations, a study was carried out in Norway among municipalities with different total drinking water hardness and different Ca/Mg ratios in the drinking water. This study has not been published, but the main results are quoted in a survey report for the Norwegian National Nutrition Council [39]. The local communities that were studied were all from the same part of Norway without any large differences in the local climate.

Unexpectedly, no correlation between drinking water Mg concentrations and cardiac mortality was found. However, a statistically significant 10% difference in age-adjusted cardiac mortality was found, comparing the municipalities with the highest and lowest drinking water Ca concentrations. Still, even in the municipalities with highest Ca levels in the drinking water, the contribution from drinking water to the total dietary Ca intake much too small, compared to the Ca intake from other foods, that drinking water Ca *per se* be the cardioprotective factor. A so-called technical effect of drinking water Ca, *e.g.,* on the rate of Pb corrosion from Pb-Sn alloys used as solder metal or from Pb-containing brass used in the water taps, was the only possible explanation [40-43].

These data from Norway are entirely consistent with the observations from England and Scotland, except that drinking water Pb concentrations must have been lower in the low-Ca communities in Norway than in the low-Ca communities in Great Britain, and the difference in cardiovascular death rates without correction for other factors were also considerably less in Norway (10% variation in Norway against variation by up to a factor of 2/1 in England and Scotland) [44].

The most important technical factor in Norway is most likely a difference in the corrosiveness of the water, which might depend not so much on the Ca^{++} concentration of the water *per se* as on its pH value. The British, however, are large consumers of tea, and most of the water that is consumed for drinking in Great Britain is boiled before it is ingested. It is then conceivable (although this hypothesis has not been experimentally tested) that when water from a limestone area in the Southeast of England is boiled, $CaCO_3$ will precipitate in the kettle during boiling, and Pb^{++} will be coprecipitated together with $CaCO_3$ because the difference in ionic radius between Ca^{++} (0.99 Å) and Pb^{++} (1.20 Å) is not so large that it would be expected entirely to hinder coprecipitation, and the solubility product of $PbCO_3$ (8.0×10^{-14}) is much smaller than that of $CaCO_3$ (4.5×10^{-9}) [45].

It is thus possible that the toxic effects of Pb may entirely explain the observed association between water hardness and cardiovascular mortality on the British Isles, perhaps both on the process of atheromatous development, on the regulation of vascular tone in the coronary vessels, on the balance between antithrombotic and prothrombotic signal substances released from endothelial cells and directly on the cardiomyocytes [46, 47]. The influence of environmental Pb can damage mitochondrial activity leading to impaired cardiovascular function [48-50].

Conclusion

The results of large epidemiologic and experimental studies show a relation between the low hardness of drinking water due to deficiency of Ca and Mg concentration, long term Pb influence, and increase of cardiovascular mortality rates. Evaluation of chronic Pb exposure regarding circulatory system diseases needs further research. Also, this problem could be solved by developing prevention programs that include the elimination of lead from drinking water and food.

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