Correlation between water hardness and cardiovascular diseases in Mostar city, Bosnia and Herzegovina

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ABSTRACT

The aim of this study was to determine the association of cardiovascular disease (CVD) of selected human subjects with the hardness of water they consume. Laboratory testing of physical and chemical parameters of water were made using standardized methods: *Standard Methods* 19th edn, 1995 (APHA, AWWA & WEF, Washington, DC), and ISO 7888:1985, ISO 10523:1998. Pearson's chi-squared test was used for the statistical analysis of data, with the significance level of 0.05. The obtained data were analysed using the statistical program SPSS 16.0. The study sample consisted of 1,021 individuals divided into two groups: soft water consumers, 603 individuals, and, hard water consumers, 618 individuals. Results indicate that a statistically significant ($\chi^2 = 5.315$; $df = 1$; $p = 0.021$) number of individuals with CVD drink soft water. The prevalence of CVD in the age group 45–60 years in the study area where soft water is consumed was 21.3% and in the study area where hard water is consumed the prevalence of CVD was 13.7%. The summary results indicate significant correlation between the prevalence of CVD in the population group who drink soft water. The value of the relative risk is 1.127.

Key words | cardiovascular disease, hard water, risk factors, soft water

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INTRODUCTION

Cardiovascular disease (CVD) is a leading cause of death in western countries. There are over 300,000 sudden deaths per year in the United States caused by CVD. Because of the importance of CVD, major efforts have been made to identify risk factors and to take steps to reduce these risks (Frost 2005). Almost 50 years have passed since the publication of the first papers suggesting an inverse association between the hardness of drinking water and cardiovascular mortality in Japan and in the USA (Catling *et al.* 2008). This was followed by a number of studies in different countries where water hardness, and later the concentration of magnesium and calcium, were used as a criterion for water quality. Several epidemiological investigations over the last 50 years have demonstrated a relation between risk of CVD development and hardness of drinking water or its content of Mg and Ca (Rylander 2008). Available data from statistical reports of the Bosnia and Herzegovina (B&H) Institute of Public Health have shown that the death rate from CVD in B&H covers 50% of all causes of mortality (Institute for Public Health Federation B&H 2010). Drinking water plays an important role in human health and well-being.

Hardness is an important water quality parameter, since increased water hardness limits its drinking suitability, as well as other purposes. Water hardness is a measure of the number of cations dissolved in the water, it is therefore, related to dissolved solids. The higher the number of dissolved cations the 'harder' the water will be. The most common cations found in water are both Ca and Mg, while iron, strontium, and manganese also contribute to hardness and are seldom present in appreciable amounts. Hardness is usually reported as an equivalent amount of calcium carbonate ($CaCO_3$) (Meena *et al.* 2012). An increasing body of evidence indicates that hardness of drinking water and elevated

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concentrations of certain minerals may reduce the risk of cardiac death and, in particular, the risk of sudden cardiac death (Frost 2005). Both Ca and Mg are essential to human health and recommended daily intakes of each element have been set at national and international levels. Inadequate intake of either nutrient can impair health; in particular it may contribute to cardiovascular disturbances (Monarca *et al.* 2006; Bo & Pisu 2008; Kupetsky-Rincon & Uitto 2012; Wang *et al.* 2012). Concentrations of up to 100 mg of Ca per litre are fairly common in natural sources of water; sources containing over 200 mg of Ca per litre are rare. Magnesium salts are water soluble; natural waters sources typically contain concentrations of up to 10 mg/L. Such sources rarely contain more than 100 mg of Mg per liter, and it is usually Ca hardness that predominates (World Health Organization (WHO) 1996; Rude 1998; Saris *et al.* 2000).

In this study, we have examined the relationship between CVD prevalence and total water hardness in the city of Mostar, B&H (urban and rural area). The results showed that there is indeed a correlation between CVD and the type of water consumed.

MATERIALS AND METHODS

Human subjects

In this study, population groups from two different areas of B&H are included with respect to the type of water (hard–soft) they consumed.

The study sample was composed of 1,221 human subjects, further divided into two groups: 603 soft water and 618 hard water consumers. The first group are residents of the Kočerin parish (rural area near Mostar city), who drink rainwater collected in special tanks. This group included all residents of Kočerin who were older than 45 years and registered in the Primary Health Care System (Kočerin health centre). The other group reside in the Mostar city (urban area), and drink water from the main supply system 'Studenac' and were randomly selected from the population, including only individuals aged over 45, and registered in the Mostar Medical Centre. Since the number of registered people in the Mostar health centre is much higher than in the Kočerin health centre, randomized trials (every third registered by alphabetical order) were extracted from medical records of the Mostar health centre. The sampled population included only people that had lived permanently in the selected areas for longer than 5 years. Investigations were carried out during the period of May to September 2010. The groups were then divided into genders and age classes for both residence areas (Table 1).

Selected groups of human subjects have statistical homogeneity in relation to age.

The data used in this study were collected from medical records, and the individuals were not subjected to any clinical trials and/or treatment, therefore the need to obtain approval from the Ethics Committee was not required for this study. Data were treated in accordance with the Helsinki Declaration.

Sampling

For this analysis, 40 water samples were taken from specialized tanks known as 'čatrnja' and 10 samples were taken from the water supply system. This ratio of samples was taken due to the high probability of variation in the analysed water parameters from the tanks. 'Čatrnje' (Figure 1) are concrete wells covered with wooden or metal lids to protect

Table 1 | Age of examined female and male population of Kočerin and Mostar

Age	Number of women (Kočerin[a])	%	Number of women (Mostar[a])	%	Number of men (Kočerin[a])	%	Number of men (Mostar[a])	%
45–60	135	39.8	126	32.8	106	40.2	87	37.7
61–75	102	30.1	159	41.1	87	32.9	82	35.5
76–90	102	30.1	102	26.1	71	26.9	62	26.8
Total:	339	100	387	100	264	100	231	100

[a]Kočerin (rainwater); Mostar city (supply system Studenac).

Figure 1 | System for rainwater collecting – 'čatrnja'.

the water from dust and other air particles. The roof gutters are connected by brass pipes to the tanks (čatrnje). When the water enters the tank, it passes through a grid which filters leaves and other impurities.

The total volume of each sample was 1 L. A half litre of each water sample was immediately preserved with 0.5 mL of 5% HNO_3, and levels of Ca, Mg and Na were determined. From the remaining 500 mL of sampled water pH, conductivity and total hardness (TH) were determined. Sampling was carried out in September 2010.

Laboratory investigations

All water samples were characterized using the following water quality parameters: temperature, pH (pH meter – Shottle Lab 850 with an accuracy of 0.01 pH units), conductivity (Conductometer, WTW LF 538 – ino Lab), Ca, Mg and Na concentrations (AAS spectrometer, AA-6300 Shimadzu, ROM version 1.03) and TH (volumetric method). All chemicals used were of analytical grade purity. Water tests were carried out using standardized methods (APHA, AWWA & WEF 1995; ISO 1985, 1998).

Cardiovascular risk factors were calculated by χ^2 analysis. Calculations were done using SPSS version 16.0 for Microsoft Windows. Significant differences were defined as having a probability value of $p = 0.05$.

RESULTS AND DISCUSSION

This study compared the prevalence of CVD in people who lived in two geographically close areas but consumed water of different hardness. The results showed that there was a correlation between prevalence of CVD and type of water consumed. Concern over water characteristics and quality as determinants of disease risk have long been considered, Hippocrates once said: 'We must also consider the qualities of the waters, for as they differ from one to another in taste in weight, so also they differ much in their qualities' (Klevay & Combs 2003). Previous studies on heart disease and water hardness have revealed strong negative correlations (Smith & Crombie 1987). According to the latest research on the impact of water hardness on mortality from CVD emphasis is given to the concentration of Mg in the water (Stevanovic & Nikic 2006). In this paper, we considered the effects of Mg, Ca and Na concentration, as well as the overall impact of the water hardness on prevalence of CVD. The results showed significant negative correlation between the prevalence of CVD and the concentration of minerals in the water. This was a pioneer study, performed in B&H, to confirm the hypothesis that: 'Water hardness is a risk factor for the development of CVD.' This work will contribute to the expansion of existing evidence concurrent with this hypothesis. If we exclude the risk factor of water hardness, and take only into account other environmental, socio-economical, psycho-social risk factors, it would be expected that individuals that reside in the urban Mostar area should have a slightly higher prevalence of CVD than people residing in the rural area of Kočerin. Regulations on hygiene, and quality of drinking water in B&H do not define the minimum and maximum concentrations of Ca and Mg or TH (Sl. Glasnik BiH br.40 2010), unlike other EU countries (e.g. Czech Republic, Hungary, Poland and Slovakia) that include minimum concentration of Ca and Mg and/or TH in the quality guidelines for drinkable water (Kozisek 2004). All four Central European countries that entered the EU in May 2004 have included the following requirements in their respective regulations but vary in binding power.

- Czech Republic (2004): for softened water ≥30 mg/L Ca and ≥10 mg/L Mg; guideline levels of 40–80 mg/L Ca and 20–30 mg/L Mg (hardness as ΣCa + Mg = 2.0–3.5 mmol/L).
- Hungary (2001): hardness 50–350 mg/L (as CaO); minimum required concentration of 50 mg/L must be met in bottled drinking water, new water sources, and softened and desalinated water.
- Poland (2000): hardness 60–500 mg/L (as $CaCO_3$).
- Slovakia (2002): guideline levels >30 mg/L Ca and 10–30 mg/L Mg.

The results of analysis of rainwater and 'Studenac' samples are given in Table 2.

If we consider the results of water analyses from the two areas in this study it is evident that the quality of water varies considerably. High average rainwater temperature (17.2 °C) is not in accordance with regulation on the hygiene of drinking water (10–12 °C). The average water temperature, from the mains (supply system Studenac), is 11.2 °C, this is not in agreement with regulation.

Independent sources of water supply are not governed by any strict sanitary protection zones, and resultant high pH 7.65 suggests the possible contamination with wastewater. There is a strong influence of soil particles and fertilizers (ammonia compounds) from the nearby gardens. Atmospheric water is slightly acidic, pH = 6.5, due to dissolution of atmospheric gases.

Since the rainwater does not come into contact with minerals in the soil it is often softer than water found in reservoirs or natural waters. However, in water samples from 'čatrnja' we detected minerals, although concentrations were significantly lower than those found in the water supply system Studenac (Table 2).

In the tested water samples, Mg mean concentration in tap water of the city of Mostar (6.32 mg/L) is close to minimum Mg concentration, 10 mg/L (Novikov *et al.* 1983; Rubenowitz *et al.* 2000) and significantly below the optimal concentration of 20–30 mg/L (Durlach *et al.* 1989; Lutai 1992).

The mean Ca concentration, 77.6 mg/L, is in agreement with the recommended optimum of 40–80 mg/L (Plitman *et al.* 1989; Rachmanin *et al.* 1990; Lutai 1992). The water consumed by residents of Kočerin is not in agreement with the recommended minimum concentration of Mg and Ca. The measured mean concentrations were 0.34 mg/L Mg and 6.32 mg/L Ca. The recommended concentration of Mg is based on its protective effects on the cardiovascular system. Changes in the metabolism of Ca and ossification were used as the basis for the recommended concentration of Ca. Estimation of the concentration is taken for long-term water consumption.

Individual mineral concentration of Ca and Mg and TH of water consumed by residents of Kočerin does not fulfil the minimum recommended values. The value of TH of water from the city of Mostar (Table 2) satisfies the recommended optimal value (minimum 100 mg/L $CaCO_3$, optimal 200–-400 mg/L) (Golubev & Zimin 1994).

The Na concentration in the water samples from both areas was extremely low, and both types of water belong to the so-called hypotensive waters (Stambuk & Stambuk 2006).

Table 2 | Results of analysis of water from two sources

	Rainwater (soft water)			Source 'Studenac' (hard water)		
Parameter	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Temperature (°C)	17.8	20.0	17.6	10.9	11.5	11.2
Conductivity (μS cm^{-1})	40.0	130	73.8	293	340	333.2
pH	7.00	8.2	7.65	7.7	7.8	7.76
TH (mg/L $CaCO_3$)	23.00	95.0	42.86	189	220	199.8
Ca (mg/L)	5.980	37.06	14.46	68.43	88.47	77.6
Mg (mg/L)	0.100	2.00	0.34	5.78	7.16	6.32
Na (mg/L)	0.370	3.10	1.19	0.86	2.87	1.55

Correlations between water hardness and the number individuals with CVD are given in Table 3.

Table 3 data were collected in a study conducted on 603 individuals who drink rainwater (soft water). In this study, 347 (57.5%) of the human subjects had been diagnosed with different types of CVD and 256 (42.5%) of them did not have CVD. Of the 618 human subjects who drink water from the water supply system Studenac (hard water), 315 (51.0%) of those were recorded as having CVD, and 303 (49%) were not suffering from CVD.

There is a statistically significant difference in the prevalence of CVD due to the hardness of the consumed water ($\chi^2 = 5.315$; $df = 1$; $p = 0.021$). An increased number of cases of CVD, occur in human subjects who consume soft water. The value of the relative risk (RR) is 1.127.

Distribution of individuals by gender and type of consumed water (Table 4) results indicate that of the total number of human subjects who drink soft water (347) and have been diagnosed with CVD, the female population is represented by 60.8% and male population by 39.2%. The total number of individuals with CVD who drink hard water was 315 with 65.1% females and 34.9% males. There was no statistically significant difference in the number of diseased human subjects who consumed soft and those who consumed hard water with regard to gender ($\chi^2 = 1.291$; $df = 1$; $p = 0.256$).

Distribution of human subjects suffering from CVD by age and hardness of the consumed water is shown in Table 5.

In the age group 45–60 years the number of patients with CVD in the study area of soft water was 74 (21.3%), whereas in the study area of hard water it was 43 (13.7%).

In the group of human subjects who drink soft water and belong to age group 61–75 years, the number of patients with CVD was 137 (39.5%), in the same age group of human subjects who drink hard water the number of patients with CVD was 147 (46.7%). In the third age group, 76–90 years, the number of patients with CVD from the soft water area was 136 (39.2%), and from the hard water area was 125 (39.7%). There is a statistically significant difference in the prevalence of CVD among human subjects who consumed a hard or soft water with respect to age ($\chi^2 = 7.500$; $df = 2$; $p = 0.023$). Statistics showed that a significantly higher number of patients, younger than 60 years, with CVD consumed soft water. In contrast, a larger number of patients, between 60 and 75 years, with CVD consumed hard water.

From the analysis of individual age groups, it can be stated that there is a statistically significant difference in the number of patients with CVD in the age group 45–60 years, due to the hardness of the water consumed ($\chi^2 = 8.214$; $df = 1$; $p = 0.004$). CVDs have higher occurrence in individuals who consumed soft water. The other age groups did not show a statistically significant difference.

Table 3 | Distribution of human subjects by consumed water type

	Number of human subjects by type of consumed water	
Diagnosed CVD	**Soft**	**Hard**
Yes	347	315
No	256	303
Total	603	618
Statistics:	$\chi^2 = 5.315$; $df = 1$; $p = 0.021$	

Table 4 | Distribution of human subjects with diagnosed CVD, by water type and gender

	Number of human subjects by type of consumed water	
Gender	**Soft**	**Hard**
Male	136	110
Female	211	205
Total	347	315
Statistics:	$\chi^2 = 1.291$; $df = 1$; $p = 0.256$	

Table 5 | Distribution of human subjects with diagnosed CVD by age group and type of water

	Type of water number of human subjects	
Age	**Soft**	**Hard**
45–60	74	43
61–75	137	147
76–90	136	125
Total	347	315
($\chi^2 = 7.500$; $df = 2$; $p = 0.023$).		

Table 6 | Distribution of human subjects by type of CVD and type of water

CVD	Type of water/Number of human subjects: Soft	Hard
Hypertension	195	178
Cardiomyopathy	64	66
Acute myocardial infarction	4	1
Ischemic heart disease	84	70
Total	347	315

The most common CVD in both groups of human subjects was hypertension (Table 6). It was found that 195 (56.2%) of 347 individuals who drink soft water have hypertension, as do 178 (56.5%) of the total 315 human subjects who drink hard water. There are no significant differences between individuals who consume soft and those who consume hard water with respect to the type of diagnosed CVD (hypertension, cardiomyopathy, ischemic heart disease and acute myocardial infarction) ($\chi^2 = 2.337$; $df = 3$; $p = 0.505$).

CONCLUSION

This study compared the prevalence of CVD in people living in two geographically close areas but consuming water of different hardness. The study included 1,221 human subjects, of which 603 daily drink soft water and 618 consume the hard water. The first group consists of residents of the parish Kočerin (rural area near Mostar city), who drink rainwater collected in special tanks. The other group of human subjects was determined from the population of the city of Mostar (urban area), who consume water from a water supply system 'Studenac'. Water used by residents of Kočerin does not satisfy even the minimum recommended concentrations of Mg and Ca individually or the recommended value for the total water hardness. The values of total water hardness and Ca concentrations in water that is consumed by the inhabitants of Mostar fulfil the recommended values, while Mg concentrations are below the recommended minimum. Sodium concentrations in water samples from both areas were extremely low, and both types of water belong to the so-called hypotensive waters. There is a statistically significant difference in the prevalence of CVD due to the hardness of the consumed water ($\chi^2 = 5.315$; $df = 1$; $p = 0.021$). CVDs occur more often in human subjects who consume soft water. The value of the RR is 1.127.

There is a statistically significant difference with respect to age in the prevalence of CVD among human subjects who consumed hard or soft water ($\chi^2 = 7.500$; $df = 2$; $p = 0.023$). There is a statistically significant difference in the number of patients with CVD in the age group of 45–60 years due to the hardness of consumed water ($\chi^2 = 8.214$; $df = 1$; $p = 0.004$). A large number of CVD patients are among human subjects who consume soft water. In the other age groups there is no statistically significant difference.

There is no statistically significant difference in the number of patients who consume soft and those who consume hard water with respect to gender ($\chi^2 = 1.291$; $df = 1$; $p = 0.256$) or to the type of CVD ($\chi^2 = 2.337$; $df = 3$; $p = 0.505$).

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