Polish J. of Environ. Stud. Vol. 20, No. 2 (2011), 411-416

Original Research

Influence of the Mineral Composition of Drinking Water Taken from Surface Water Intake in Enhancing Regeneration Processes in Mineralized Human Teeth Tissue

Ryta Łagocka[1], Jolanta Sikorska-Bochińska[1], Iwona Noceń[2], Katarzyna Jakubowska[3], Monika Góra[1], Jadwiga Buczkowska-Radlińska[1]*

[1]Department of Conservative Dentistry,
[2]Department of Medical Chemistry,
[3]Department of Biochemistry,
Pomeranian Medical University, Powstańców Wlkp. 72, 70-111 Szczecin, Poland

Received: 17 May 2010
Accepted: 5 October 2010

Abstract

The purpose of our study was to assess whether the chemical composition of drinking water in the city of Szczecin, Poland, creates the correct environment in the oral cavity for promoting regeneration processes in the mineralized tissue of teeth.

The drinking water samples were collected from a water treatment station, as raw and treatment water, and from consumer's water pipes. The concentration of calcium and magnesium was determined by F-AAS method, fluoride by ion-specific electrode, and pH by pH-Meter.

The average concentrations of calcium (46.9 mg/dm^3), fluoride (0.73 mg/dm^3), and pH level (7.46) determined in tap drinking water create a sufficient environment in the oral cavity for promoting regeneration processes in tooth mineralized tissues. Because of the low concentrations of magnesium in drinking water (14.1 mg/dm^3), this element should be supplemented in a person's diet.

Keywords: enamel remineralization, calcium, magnesium, fluoride, drinking water

Introduction

The physicochemical integrity of enamel in the environment of the oral cavity is determined by the chemical composition of the liquids surrounding it, i.e. saliva and plaque in its liquid phase. De- and remineralization processes are constantly taking place on the surface of the enamel of human teeth, as a consequence of changes in its immediate surrounding it [1, 2]. Solutions supersaturated with respect to dental hard tissue will not dissolve tooth mineral. The hydroxyapatite begins to dissolve when the solution surrounding it becomes unsaturated as a result of the removal from it of one or many ions. The more ions removed, the faster the dissolution process proceeds. The process of demineralization continues each time there is carbohydrate taken into the mouth. Any fermentable carbohydrate can be metabolized by acidogenic bacteria and create the organic acids as byproducts. The acids diffuse through plaque and into the porous subsurface enamel (or dentin, if exposed), dissociating to produce hydrogen ions as they travel. The hydrogen ions readily dissolve the mineral, freeing calcium and phosphate into solution, which can diffuse out of the

*e-mail: zstzach@sci.pam.szczecin.pl

tooth [3]. Demineralization also plays a role in surface dissolution of dental hard tissues by acids without the involvement of micro-organisms. This process is called dental erosion, and may be caused by a series of extrinsic and intrinsic factors. Extrinsic factors largely include the consumption of acidic foods and carbonated beverages, citrus fruits and, to a lesser degree, occupational exposure to acidic environments. The most common intrinsic factors include chronic gastro-intestinal disorders such as gastro-oesophageal disease, as well as health issues like anorexia and bulimia [4]. The dynamic of the hydroxyapatite dissolution decreases until it stops completely at the moment, when the saliva becomes saturated once more with phosphate, hydroxide, and calcium ions. Saliva has a critical role in the prevention or reversal of the tooth demineralization process. Its components neutralize the acids produced by bacterial metabolism in plaque, raise pH, and reverse the diffusion gradient for calcium and phosphate. The pH level of saliva and its saturation with calcium and phosphate salts together with the presence of fluoride, are important agents for promoting repair of mineralized tissue in the oral cavity in the process called remineralization [1, 2].

Two of the extrinsic factors that can change the pH level and concentrations of ions in the environment surrounding the teeth are food and liquids consumed by humans, including tap water. Changes in the physicochemical properties of drinking water may affect the mineralized tissue of the oral cavity in two ways. Firstly, through their systemic impact on calcium, magnesium, and fluoride homeostasis, which is reflected in the concentration of these components secreted with saliva; and, secondly, through their local impact on the tissue of teeth when drinking water and consuming food prepared on a water base. Of all the mineral components that can appear in drinking water, only fluoride compounds have been researched in depth and their influence on the mineralized tissue of teeth is well known [1, 2, 5-8]. The relationships between the mineral composition of drinking water, especially water hardness, calcium, and magnesium content, and its effect on the resistance and susceptibility of teeth to demineralization, has been researched sporadically. In 1937 Mills showed that, among 75 cities in the US, those having the highest drinking water hardness had the lowest numbers of decayed, missing, and filled tooth surfaces (DMF-S) [9]. In 1973 Glass et al., in two isolated villages in Colombia, also identified calcium as carrying a protective element in drinking water [10]. Only Bruvo et al. showed that calcium and fluoride together explained 45% of the variations in the numbers of decayed, filled, and missing tooth surfaces among schoolchildren in Denmark. Both ions in drinking water had reducing effects on DMF-S independent of each other [6]. The literature lacks reports dealing with the effects of calcium and magnesium concentration in drinking water on dental de- or remineralization processes in the Polish population.

The aim of this work was to assess whether the mineral composition of drinking water in the city of Szczecin creates the right environment in the oral cavity for promoting the repair of mineralized tooth tissue.

Materials and Methods

The main source of water intended for human consumption and communal needs in the city of Szczecin is the surface water intake from Lake Miedwie. The water in Lake Miedwie is equivalent to Class II purity [11]. The first group of drinking water samples were collected from the Miedwie Water Treatment Station before the water disinfection processes. The samples were obtained directly from a water pump after allowing the water to run for at least five minutes – group A. The second group of samples was also collected in the station, but after water disinfection processes that consisted of the following technological processes: preliminary oxidization with ozone (coagulation, flocculation, sedimentation, filtration) and secondary oxidisation with ozone (filtration based on active carbon, disinfection with chlorine dioxide) – group B. Nine water samples each were taken from groups A and B. The finished drinking water samples were collected for analysis from consumers' water pipes in different districts in Szczecin. The samples were taken in two ways: the first group of samples was taken from the first water to run from the tap in the morning after the night (group C); the second group of samples was taken after letting the water from the tap run for two minutes (group D). 30 water samples each were taken from groups C and D. The drinking water samples were collected in polyethylene bottles. The samples were subsequently stored at 4ºC for as short a time as possible before analysis to minimize physicochemical changes. In all water samples the pH level and concentrations of calcium, magnesium and fluoride were determined. The calcium and magnesium concentrations were determined on the basis of the atomic absorption spectrometry method using a Philips PU 9100X Atomic Absorption Spectrometer [12]. The fluoride concentration in water samples was determined directly after being diluted with equal volumes of a TISAB buffer using a fluoride-specific electrode (Beckman 39848). pH was measured with a Beckman pH Meter.

All the measurements were made at the Department of Biochemistry and Department of Medical Chemistry, Pomeranian Medical University in Szczecin.

A statistical comparison was carried out using the Mann-Whitney U-test, taking $p \leq 0.05$ as the level of significance.

Results

The bacteriological, physicochemical, and organoleptic norms that drinking water should meet in Poland are set by the Ordinance of the Ministry of Health of 29 March 2007 [13]. The ordinance specifies, among other things, the acceptable range of concentrations of calcium, magnesium, and fluoride in drinking water, as well as the acceptable pH level. These values represent the reference point for this study.

The average concentrations of calcium and magnesium contained in the drinking water samples taken from the

Table 1. Concentrations of calcium and magnesium in drinking water samples taken from the Miedwie surface water intake in Szczecin in relation to regulatory norms.

Parameter	Permissible range of values	Group			
		A n=6	B n=6	C n=30	D n=30
Calcium mg/dm³	60-500 as $CaCO_3$ (i.e. 24-200 as calcium)				
x		46.5	42.7	42.8	46.9
SD		9.2	5.5	3.2	5.4
min		38.7	36.9	36.8	38.8
max		61.2	52.5	47.7	61.2
Magnesium mg/dm³	30-125				
x		11.0	9.5	13.0	14.1
SD		3.8	2.2	2.9	2.7
min		7.1	6.7	7.1	8.4
max		15.8	12.7	17.3	16.8

x – mean, SD – standard deviation

Miedwie surface intake in Szczecin in relation to regulatory norms are presented in Table 1. In none of these samples did the calcium concentrations exceed regulatory norms. Nor were any statistically significant differences noted between the researched groups. The average concentration of calcium in the water reaching inhabitants amounted to 42.8 and 46.9 mg/dm³, respectively, in groups C and D. The magnesium concentrations obtained from all the researched samples were below the norms prescribed in Polish legislation, which set the minimum and maximum concentrations of magnesium depending on the presence of sulphate ions in the water at the same time. However, they do not require the water producer to supplement any deficiencies in this element. The concentration levels of magnesium do not vary statistically significantly between the researched groups.

The researched pH of water taken from the surface water intake at Miedwie in Szczecin in relation to the binding norms is presented in Table 2. No statistically significant differences were noted between the researched groups. In all the researched samples the pH balance of water ranged from neutral to very slightly alkaline. The lowest obtained pH value was 7.0, and the highest was 7.98. In neither of the researched samples was the pH level acidic.

The average concentration of fluoride in the researched water samples in relation to the binding norms is presented in Table 3. The concentrations of fluoride noted in all the researched samples did not exceed the legislatively set boundary value of 1.5 mg/dm³. All samples of raw and treatment water (group A and B) contained an average fluoride value of 0.34 and 0.37, respectively. An increase in the mean concentrations of fluorides to 0.9 and 0.73 mg/dm³, respectively, was observed in groups C and D. In

Table 2. pH value in drinking water samples taken from the Miedwie surface water intake in Szczecin in relation to regulatory norms.

Parameter	Permissible range of values	Group			
		A n=6	B n=6	C n=30	D n=30
pH	6.5-9.5				
x		7.35	7.53	7.42	7.46
SD		0.31	0.22	0.22	0.27
min		7.0	7.05	7.1	7.02
max		7.6	7.7	7.85	7.98

x – mean, SD – standard deviation

Table 3. Concentration of fluoride in drinking water samples taken from the Miedwie surface water intake in Szczecin in relation to regulatory norms.

Parameter	Permissible range of values	Group			
		A n=6	B n=6	C n=30	D n=30
Fluoride mg/dm³	0.0-1.5				
x		0.34	0.37	0.9	0.73
SD		0.1	0.1	0.57	0.41
min		0.27	0.36	0.35	0.3
max		0.4	0.4	1.1	0.75

x – mean, SD – standard deviation

some of the water samples from group C the concentration of fluoride exceed the value 1 mg/dm³. However, there were no statistically significant differences in the concentration of fluoride between the groups. It was noted that the concentration of fluoride was only higher in the water samples taken from taps which were the final intakes of drinking water in old 19th century buildings.

Discussion

The ordinance regarding water quality indicates the lower range of water hardness as 60 mg $CaCO_3$/dm³, which corresponds to about 24 mg Ca/dm³ [13]. Higher than borderline concentrations of minerals in drinking water reduce the risk of changes in human metabolism [14-17]. The correct concentration of calcium and magnesium in drinking water through its impact on systemic homeostasis can have an effect on the concentration of these elements in saliva. The disorders of calcium homeostasis are connected with high caries intensity, which was shown in research carried out by Moschen et al. [18]. The calcium present in the saliva is of plasmatic origin [19]. Its concentration increases to a slight degree in tandem with the speed at which saliva is secreted. With a neutral pH level the ionized calcium represents half the value of the calcium as a whole, but this amount increases as the pH level declines, and when the pH value falls below 4 the ionized calcium is in the overwhelming majority [20, 21]. The ionized calcium helps establish equilibrium between the hydroxyapatite of the mineralized tissue of teeth and fluids in the oral cavity. An essential condition for repairing initial damage to enamel is saturation of the saliva with calcium and phosphate salts. A neutral pH level in saliva and dental plaque makes possible a diffusion of ions toward damaged hydroxyapatite crystals and also supports the latter's reconstruction [1-4]. The important roles played by calcium and phosphate ions in the remineralization of enamel was confirmed by Larsen et al. and by Hara et al. [22, 23]. According to Larsen et al., the carious process is reversible in cases of sub-surface enamel damage thanks to remineralization, i.e. through the reconstruction of partially dissolved crystals, and an essential condition for achieving this is saliva, saturated with calcium and phosphate salts [22].

In order to achieve full remineralization of enamel, with pH 7, the liquid surrounding enamel should contain 1 mmol Ca/dm^3. In concentrations that are three times higher, remineralization is restricted to the surface layer of enamel and the creation of a diffusion barrier that makes deep penetration of enamel and phosphates, and thus complete mineralization, impossible [24]. According to Wilson et al., artificially augmenting the content of calcium in dental plaque can have a positive influence on checking the advance of caries [25]. Research carried out by some authors confirmed that the populations of cities that drink hard water have the lowest index of caries [6, 9, 10]. As Bruvo et al. suggest, calcium contained in drinking water can promote remineralization and reduce demineralization in the initial stages of caries [6]. This effect may be due to the positive union of calcium ions with fluoride ions in dental plaque. In this way, calcium may diffuse into plaque and provide extra binding sites for fluoride. We determined that the supply of drinking water with 0.75 mg/dm^3 fluoride and 90 mg/dm^3 of calcium will result in a substantial reduction in DMF-S [6]. It appears, therefore, that the concentration of calcium in saliva, in combination with a pH level of 7, to create a positive environment for repairing initial damage of dental enamel, cannot be less than 40 mg Ca/dm^3 and higher than 90 mg Ca/dm^3. In this study, the concentration of calcium in drinking water taken from consumers' water pipes were within the limits of 36.8-47.7 mg/dm^3 in group C and 38.8-61.2 mg/dm^3 in group D (Table 1), and were thus sufficient to promote remineralization processes in the oral cavity, especially as the pH of the researched water samples promoted regeneration processes (Table 2).

The recommended concentration of magnesium in drinking water depends on the content of sulphate ions accompanying it, and should amount to 30 to 125 mg Mg/dm^3 [5, 13]. As was obtained in the study (Table 1), water from the "Miedwie" intake in the city of Szczecin had a lower than recommended concentration of magnesium. The 2007 ordinance does not impose on water producers any obligation to supplement the minimum content of this element, despite the fact that magnesium deficiency can be supplemented by consuming water containing a minimum of 50 mg/dm^3 of this element [13, 15-17]. The data presented in Table 1 show that for general health reasons, inhabitants of Szczecin should consume water and food enriched in assimilable magnesium. To maintain the mineral equilibrium of the surface layers of enamel, however, low concentrations of magnesium in water directly washing against the teeth in the oral cavity do not have a negative impact. This is because higher concentrations of magnesium ions may inhibit the growth of hydroxyapatite crystals through the stabilization of amorphous magnesium phosphate [26, 27].

To meet qualitative requirements, drinking water should have a pH value between 6.5 and 9.5 [13]. The integrity of the enamel hydroxyapatite is preserved when the pH of the liquids surrounding it is above 5.5. The borderline pH value for fluoroapatite is 4.5, but for root cement it is only 6.7 [1]. The local action of even slightly acidic drinking water solution may thus be especially negative for older people susceptible to root cement caries. During the course of this research, the pH value in all tested water samples was neutral, inclining toward alkaline (Table 2). It thus created positive conditions promoting remineralization processes in the environment of an oral cavity.

According to the 2007 ordinance, the content of fluoride in the drinking water should not exceed the limit of 1.5 mg/dm^3 [13]. Due to increased fluoride pollution of the environment, the World Health Organization does not prescribe supplementing fluoride in areas where the concentration of fluoride in drinking water is over 0.7 mg F/dm^3. In Poland the recommended fluoride concentration is 0.3 mg/dm^3 or higher [14]. Fluoride has important anti-carious effects. There is strong evidence that water fluoridation improves and considerably reduces inequality in dental health [3, 8]. But fluoride is also one of the etiological factors causing enamel developmental anomalies [8, 28]. Disturbances in enamel mineralization can occur even when the fluoride concentration in drinking water is suboptimum [28]. In meta-analysis conducted by McDonagh et al., the prevalence of fluorosis at a water fluoride concentration at 1.0 ppm was 48% and for fluorosis of aesthetic concern 12.5% [8]. The toxic effect of the fluoride can be potentially increased as a consequence of exposure to different sources: air, food, drinks, or fluoridated dental products [28-31]. In current thinking on caries prophylaxis the exogenous use of fluoride compounds is regarded as more important than their endogenous supply. Research conducted on models simulating de- and remineralization processes showed that a concentration of fluoride above 0.03 mg/dm^3 accelerates remineralization. The local application of fluoride toothpaste initially results in a very high concentration of fluorine in saliva, which then declines, but for several hours is maintained at 0.03-0.1 mg/dm^3, thereby increasing remineralization [32]. The protective action of fluoride in drinking water on the dental tissue may involve maintaining the minimum concentration of fluoride in saliva essential for the remineralization of enamel. In this research the fluoride concentration in drinking water samples was sufficient to support this profitable process (Table 3). Because of the universal use of toothpaste with fluoride as well as the pollution of Szczecin's natural environment, the endogenous supply of fluoride, e.g. in drinking water, should be restricted. According to Table 3, higher concentrations of fluorides were noted in drinking water taken from taps (group C and D) in some parts of the city of Szczecin. Moreover, the concentrations of fluorides in these samples were not over the legal limit, but concentrations of fluorides over 1 mg/dm^3 can be a significant factor in calculating total daily fluoride exposure, and may be responsible for the toxic effects of this element on the human body. It also shows harmful changes that the drinking water undergoes while passing through the water-pipe network. [5, 14, 33]. The state of the water distribution networks in buildings also influences the quality of water, especially in districts where the water-pipe network is 50 to 100 years old. Such facilities are usually in poor technical condition and suffer from a high incidence of breakdowns and interruptions in the water supply, variations in pressure, and corrosion [5]. It can also be responsible for increasing the concentration of fluorides in water samples taken in the morning, without previously letting the tap run for a few minutes. Limiting the supply of fluorides, which cause secondary impurities in water, is difficult because most carbon filters are unable to eliminate them [34]. As shown in Table 3, the concentration of fluorides in drinking water decreases when samples are taken after some time, when some night water is taken away from the installation (Table 3).

Conclusion

Drinking water from the surface water intake reaching Szczecin does not pose a threat to the stability of enamel apatites. Its pH level as well as the concentrations of calcium and fluoride contained in it create a positive environment in the oral cavity for promoting regeneration processes in the mineralized tissue. Due to this fact, it can be recommended for mouth rinsing in people who are on diets that increase the likelihood of tooth erosion. The increased concentration of fluoride in certain water samples suggests that water for consumption purposes be taken from the tap only after letting the tap run for a few minutes after remaining untouched during the night. Low concentrations of magnesium in drinking water suggest that diets should be supplemented with this element.

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