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Low-mineral direct drinking water in school may retard height growth and increase dental caries in schoolchildren in China

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ABSTRACT

Although direct drinking water (DDW) systems that utilize a reverse-osmosis technique are thought to be harmful to children's development by reducing their daily mineral intake, few population data are available regarding this topic. We conducted an eco-epidemiological study to investigate the influence of low-mineral DDW on the development of schoolchildren. We collected developmental parameters of 13,723 girls and 16,161 boys before and after the introduction of DDW systems in 25 schools and measured the mineral levels in the DDW of each school. The DDW in 22 schools had lower-than-recommended levels of magnesium and calcium (magnesium, 10 mg/L and calcium, 20 mg/L, WHO). We found that children exposed to low-mineral DDW exhibited reduced height and diminished height increases as well as higher prevalences and incidences of hypoevolutism and dental caries ($p < 0.01$). This exposure was a risk factor for a greater incidence of both hypoevolutism and dental caries in children (RR = 7.110 (1.688, 29.953) and 1.813 (1.309, 2.509), respectively; $p < 0.01$). Our results suggest that low-mineral DDW may retard height growth and promote the incidence of dental caries in schoolchildren; thus, schools should choose DDW treatment systems that retain the minerals in water.

1. Introduction

Schoolchildren nearing puberty are in an important period of bone growth and mineral acquisition (Sowinska-Przepiera et al., 2011; Ward et al., 2014). A sufficient supply of mineral compounds, including calcium, is important for their development. Unfortunately, many studies have shown that the recommended daily intake of minerals is not satisfied via food consumption in children, including in China (Zhang et al., 2013; Zhou et al., 2015). In Chongqing, the calcium intake of children from their diets was only 480 mg (± 80 mg) per day (Gu et al., 2012), much lower than the recommendations of Chinese children (1000–1200 mg/d in 7–11 years old children) (Chinese Nutrition Society, 2014). Thus, other sources of calcium are essential to prevent adverse effects induced by a low-calcium diet (Bruvo et al., 2008; Centeno et al., 2009; Joyce et al., 2005; Lee et al., 2008; Madej et al., 2011; Martinez-Ferrer et al., 2008; Rylander, 2008). The calcium present in drinking water should be considered an important means of mineral supplementation for these children, as its bioavailability is similar to that from dairy products. However, in many area of China, to ensure the quality of classically produced tap water, the government has widely implemented direct drinking water (DDW) systems on school campuses. DDW, also known as fine drinking water, is obtained from municipal tap water using a series of advanced water treatment technologies and can be consumed safely without another treatment. According to our preliminary investigation, reverse-osmosis technology, which almost completely removes minerals as well as harmful substances, is adopted in the majority of DDW systems (Huang et al., 2015). Our study also demonstrated a significant reduction in the mineral levels of DDW, including calcium, in schools that introduced DDW systems (Huang et al., 2015).

Drinking low-mineral water can lead to various health risks, including osteopenia (Frantisek, 2005). Our previous study also indicated that low-mineral water was associated skeletal degradation in female rats (Qiu et al., 2015). Since schoolchildren in China spend most of their time at school (> 10 h per day), the DDW they drink at school accounts for a significant proportion of their water consumption. The lack of

Abbreviations: DDW, direct drinking water

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Table 1
Distribution of the study subjects.

Year recruited	Age (years)	Girls	(n)	Boys	(n)	Total	(n)
		Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
2008	10	89	508	119	558	208	1066
	11	115	571	107	634	222	1205
	12	74	327	91	450	165	777
	Total	278	1406	317	1642	595	3048
2009	10	572	1492	562	1593	1134	3085
	11	492	1287	556	1421	1048	2708
	12	71	254	142	396	213	650
	Total	1135	3033	1260	3410	2395	6443
2011	10	506	1388	575	1527	1081	2915
	11	175	531	273	796	448	1327
	12	179	575	310	793	489	1368
	Total	860	2494	1158	3116	2018	5610
2012	10	514	1473	630	1577	1144	3050
	11	469	1525	497	1689	966	3214
	12	102	434	188	677	290	1111
	Total	1085	3432	1315	3943	2400	7375

Table 2
Mineral contents of DDW.

Analyte	Group 1 (3 schools) Mean ± SD	Group 2 (22 schools) Mean ± SD (n = 22)	p	Tap water
Calcium (mg/L)	46.33 ± 6.78	3.41 ± 2.38	< 0.001	52.20
Magnesium (mg/L)	10.09 ± 0.80	0.85 ± 0.46	< 0.001	12.50
Sodium (mg/L)	12.87 ± 3.81	2.27 ± 2.44	< 0.001	12.70
Potassium (mg/L)	0.91 ± 0.11	0.31 ± 0.31	< 0.001	2.50
Chlorides (mg/L)	18.00 ± 1.81	4.56 ± 4.74	< 0.001	16.00
Sulfates (mg/L)	50.18 ± 15.11	8.47 ± 14.42	< 0.001	48.20
Fluorides (mg/L)	0.23 ± 0.04	0.10 ± 0.07	< 0.001	0.20
Bicarbonate (mg/L)	102.03 ± 4.84	19.58 ± 12.28	< 0.001	161.04
Hardness ($CaCO_3$, mg/L)	145.13 ± 7.43	24.49 ± 8.76	< 0.001	200.30
Conductivity (μS/cm)[a]	355.63 ± 84.09	53.12 ± 26.64	< 0.001	409
pH[b]	7.65 ± 0.33	7.34 ± 0.22	0.035	7.57

[a] From 2009 to 2013.
[b] From 2009 to 2012.

Table 3
BMI (kg/m^2, means ± SD (n)) of children in 2008, 2009, 2011, and 2012.

		Girls			Boys		
Year	Age	Group 1	Group 2	p	Group 1	Group 2	p
2008	10	18.3 ± 3.3(89)	18.6 ± 3.2(508)	0.330	18.4 ± 3.1(115)	18.2 ± 2.9(571)	0.512
	11	18.4 ± 3.1(115)	18.2 ± 2.9(571)	0.512	17.6 ± 3.1(74)	18.3 ± 3.2(327)	0.105
	12	17.6 ± 3.1(74)	18.3 ± 3.2(327)	0.105	18.4 ± 3.4(119)	18.8 ± 3.3(558)	0.244
2009	10	18.4 ± 3.2(572)	18.6 ± 3.2(1492)	0.270	18.6 ± 3.1(492)	18.6 ± 3.1(1287)	0.867
	11	18.6 ± 3.1(492)	18.6 ± 3.1(1287)	0.867	17.7 ± 2.7(71)	18.3 ± 3.0(254)	0.111
	12	17.7 ± 2.7(71)	18.3 ± 3.0(254)	0.111	18.4 ± 3.2(562)	18.7 ± 3.4(1593)	0.088
2011	10	18.2 ± 3.2(506)	18.2 ± 3.1(1388)	0.897	17.9 ± 2.3(175)	18.2 ± 3.2(531)	0.101
	11	17.9 ± 2.3(175)	18.2 ± 3.2(531)	0.101	18.5 ± 3.0(179)	18.5 ± 3.3(575)	0.926
	12	18.5 ± 3.0(179)	18.5 ± 3.3(575)	0.926	18.1 ± 2.8(575)	18.4 ± 3.1(1527)	0.028
2012	10	18.2 ± 3.0(514)	18.1 ± 2.9(1473)	0.715	18.1 ± 2.9(469)	18.4 ± 3.1(1525)	0.098
	11	18.1 ± 2.9(469)	18.4 ± 3.1(1525)	0.098	17.8 ± 2.5(102)	18.8 ± 9.1(434)	0.274
	12	17.8 ± 2.5(102)	18.8 ± 9.1(434)	0.274	18.2 ± 2.9(630)	18.0 ± 3.0(1577)	0.217

minerals such as calcium in DDW may result in the loss of minerals obtained from drinking and affect the development of children.

Dental caries is one of the most prevalent chronic diseases worldwide. Although people are susceptible to the disease throughout their lifetime, dental caries often arises in childhood as aggressive tooth decay (Selwitz et al., 2007). Dental caries is the primary cause of oral pain and eating difficulty and can even lead to inflammation of the tissue around the tooth, tooth loss, and infection or abscess formation (Laudenbach and Simon, 2014). However, the disease can be arrested and potentially reversed in its early stages (i.e., in childhood) and usually is not self-limiting if without proper care. As caries will progress until the tooth is destroyed (Selwitz et al., 2007), it is necessary to clarify its causes. This disease may results from interactions between bacteria and many host factors, including insufficient mineral exposure (Riyat and Sharma, 2010; Selwitz et al., 2007). In DDW, the lack of calcium, which is the major constituent of teeth, and other minerals such as fluoride that are beneficial to dental caries prevention may increase the incidence of dental caries.

To investigate the effect of low-mineral DDW on the physical development and dental health of schoolchildren, we selected 25 schools