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Drinking Deep Seawater Decreases Serum Total and Low-Density Lipoprotein–Cholesterol in Hypercholesterolemic Subjects

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ABSTRACT Drinking deep seawater (DSW) with high levels of magnesium (Mg) decreased serum lipids in animal studies. Therefore the effects of drinking DSW on blood lipids and its antioxidant capacity in hypercholesterolemic subjects were investigated. DSW was first prepared by a process of filtration and reverse osmosis, and then the concentrated DSW with high levels of Mg was diluted as drinking DSW. Forty-two hypercholesterolemic volunteers were randomly divided into three groups: reverse osmotic (RO) water, DSW (Mg: 395 mg/L, hardness 1410 ppm), and magnesium-chloride fortified (MCF) water (Mg: 386 mg/L, hardness 1430 ppm). The subjects drank 1050 mL of water daily for 6 weeks, and blood samples were collected and analyzed on weeks 0, 3, and 6. Drinking DSW caused a decrease in blood total cholesterol levels and this effect was progressively enhanced with time. Serum low-density lipoprotein–cholesterol (LDL-C) was also decreased by DSW. Further, total cholesterol levels of subjects in the DSW group were significantly lower than those in the MCF water or RO water groups. Compared with week 0, the DSW group had higher blood Mg level on weeks 3 and 6, but the Mg levels were within the normal range in all three groups. DSW consumption also lowered thiobarbituric acid-reactive substances (TBARS) values in serum. In conclusion, DSW was apparently effective in reducing blood total cholesterol and LDL-C, and also in decreasing lipid peroxidation in hypercholesterolemic subjects.

KEY WORDS: • ***antioxidative*** • ***deep seawater*** • ***hypocholesterolemic effect*** • ***magnesium***

INTRODUCTION

DEEP SEAWATER (DSW) is clean, sanitary, and characterized by low temperature, nonpathogenic, abundant nutrients, and high content of minerals such as, magnesium (Mg), calcium (Ca), potassium (K), *etc*.[1–3] In recent years, DSW has been widely used in various industries, such as food processing, agriculture, and the pharmaceutical and cosmetic industries. Cardiovascular disease and cerebrovascular diseases are major causes of mortality in developing countries, and the second and third highest causes of mortality in Taiwan, respectively. There are a number of factors involved in the etiology of cardio-cerebrovascular diseases, but undeniably, the primary factor is atherosclerosis. As hypercholesterolemia is the major cause of atherosclerosis, a treatment for hyperlipidemia would be of obvious benefit for the prevention of atherosclerosis.

Animals studies show that administration of DSW to rabbits fed a high-cholesterol diet resulted in decreases in blood total cholesterol and low-density lipoprotein–cholesterol (LDL-C) levels, and accelerated the reduction of blood lipid concentrations in hyperlipidemic rabbits.[4] Moreover, Kimura *et al*.[3] pointed out that higher Mg (600 and 1000 ppm) water made from DSW decreased cholesterol by 18% and 15%, respectively, and may be a useful natural drink to improve lipid metabolism and to prevent atherosclerosis in rats. Recent study showed that mice given DSW experienced lower blood total cholesterol and triacylglycerol concentration when compared with those given pure water.[5] Drinking of DSW, therefore, appeared to alleviate the myocardial injuries caused by a high lipid/cholesterol diet. On the other hand, DSW was suggested to have a potential role as an anti-obesity agent and might play beneficial roles in glucose metabolism.[6–7]

Epidemiological studies show that Mg depletion in drinking water is associated with the risk of cardiovascular diseases[8–9] and this effect was attributed to the protective effect of high content of Ca and Mg, indicating that Mg was protective against acute myocardial infarction. Recently, Kishimoto *et al.*[10] showed that Mg supplementation could improve postprandial hyperlipidemia in healthy subjects. Moreover, Mg intake is inversely associated with prevalence of the metabolic syndrome and oxidative stress.[11] These results indicate that the hardness of drinking water, especially its Mg content, is associated with retarding the development of cardiovascular diseases.

To date, to the best of our knowledge, there is no report describing the effect of DSW on lipid metabolism in a

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human study. In the present study, we investigated the effect of the intake of DSW rich in Mg, at a degree of hardness of 1400 ppm prepared from concentrated DSW, for 6 weeks on lipid metabolism and its antioxidant capacity in hypercholesterolemic subjects.

SUBJECTS AND METHODS

Materials

DSW was obtained from the Pacific Ocean at a depth of 662 m, at a distance of 5 km off the coast of Hualien County, Taiwan. The obtained water was subjected to a process of filtration, reverse osmosis, and concentration. The concentrated DSW had a hardness of 300,000 mg/L and Mg content was 75,000 mg/L.

Water for this experiment included: (1) reverse osmotic (RO) water, produced by reverse osmosis of DSW; (2) DSW, obtained by diluting the concentrated DSW with RO water to achieve a Mg concentration of 350 mg/L and hardness of 1400 mg/L; and (3) Magnesium-chloride fortified (MCF) water, obtained by dissolving magnesium chloride hexahydrate ($MgCl_2 \cdot 6H_2O$, purity 98%) in RO water to get a similar Mg content to that of DSW. All water used in the experiment was pasteurized and bottled and provided by Taiwan Yes Deep Ocean Water Co., Ltd.

Subjects

Between April 2009 and November 2009, 42 hypercholesterolemic individuals (23 men and 19 women) were selected from a population in Northern Taiwan for this 6-week study at Cardinal Tien Hospital in Yung Ho (New Taipei City, Taiwan). Inclusion criteria for the study were serum total cholesterol > 200 mg/dL and LDL-C > 130 mg/dL, 30–65 years old and BMI between 22 and 28 kg/m^2. No subjects in this study had a history of cardiovascular diseases, diabetes, chronic inflammation, liver/kidney disease, or hypothyroidism. None of the subjects used herbal medicines, or took supplements such as Monascus, phytosterols, or fish oil, which are known to affect blood lipid levels.

The subjects accepted into the study were requested to maintain their regular diet and exercise regimen. They were instructed to avoid social drinks and to limit alcohol consumption to less than 2 servings/day. The volunteers were informed about the content and detailed procedures of the study, and signed consent was obtained from all subjects prior to participation in the study. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and the protocol was approved by Fu Jen Catholic University's Institutional Review Board.

Experimental design

The experiment was conducted using double-blind, randomized controlled DSW supplementation. The subjects were randomly divided into three groups as follows: (1) RO group (7 men and 7 women), (2) DSW group (10 men and 4 women), and (3) MCF water group (6 men and 8 women).

Table 1. Mineral and Salt Contents of Reverse Osmosis Water, Deep Seawater, and $MgCl_2$ Fortified Water Used in the Study

Mineral/salt	*RO water (mg/L)*	*DSW (mg/L)*	*MCF water (mg/L)*
Sodium	1.15	33.1	13.5
Magnesium	1.3	395	386
Potassium	ND	35.7	6.24
Calcium	1.08	6.58	6.7
Fluorine salt	ND	0.13	< 0.10
sulfate salt	ND	167	0.61
Hardness	8	1410	1430

Analyzed by SGS Taiwan Ltd. The levels (ppb) of trace elements in DSW were, lithium 48.8, selenium 8.69, silicon 4.02, molybdenum 2.81, zinc 1.61, and strontium 1.93.

RO water, reverse osmotic water; DSW, deep seawater; MCF water, magnesium-chloride fortified water; ND, not detectable.

All subjects in this study drank three bottles of water (350 mL/bottle) daily, for a total volume consumed daily by each subject of 1050 mL. The amount of Mg in the water was equivalent to the Recommended Daily Allowance (RDA). Subjects were advised to consume one bottle of water every morning, afternoon, and evening, and to try to finish drinking each bottle of water by drinking from the bottle 3–4 times. Mg concentrations in RO water, DSW and MCF water were 1.3, 395 and 386 mg/L, respectively. The hardness concentrations of the water were: 8 ppm for RO, 1410 ppm for DSW, and 1430 ppm for MCF (Table 1).

Blood sampling and serum lipid and mineral analysis

Blood samples were collected into vacuum tubes without anticoagulants on weeks 0, 3, and 6, between 9:00 and 10:00 after 10- to 12-hour fasting. Samples were centrifuged at 1400 *g* for 15 min and serum was collected. Serum samples were kept at $-80°C$ for further analysis as previously reported.[12]

Commercial enzymatic kits (Randox Lab., Ltd.) were used to analyze serum total cholesterol, LDL-C, and high-density lipoprotein–cholesterol (HDL-C)[13] and triacylglycerols.[14] Serum thiobarbituric acid-reactive substances (TBARS) were measured by the method of Oteiza *et al.*,[15] using tetraethoxypropane as the standard. Total antioxidant status of serum was analyzed according to the method of Miller *et al.*[16] and expressed as trolox equivalent antioxidant capacity. Alanine aminotransferase (ALT), aspartate aminotransferase (AST) and blood urea nitrogen (BUN) were measured using commercial kits (Randox). The mineral levels of serum Mg and Ca were measured using commercial kits (Randox). Sodium (Na) and K concentration of serum were analyzed by atomic absorption spectroscopy.

Basic characteristics and food intake

Anthropometric data were collected from all subjects in the study. At the beginning (week 0) and at the end (week 6) of this study, food intake was recorded for three consecutive days (one was required to be a holiday or Saturday/Sunday).

Table 2. Baseline Characteristics of the Study Subjects

	Groups		
Parameter	*RO water*	*DSW*	*MCF water*
Age (years)	45.6 ± 10.1	46.9 ± 8.6	49.0 ± 8.7
Height (cm)	164.1 ± 9.7	164.9 ± 9.9	164.2 ± 7.7
Body weight (kg)	68.6 ± 16.6	68.8 ± 11.6	69.0 ± 11.7
Waist circumference (cm)	86.9 ± 8.3	86.2 ± 7.7	86.3 ± 8.0
Hip circumference (cm)	98.6 ± 8.0	98.0 ± 5.2	98.5 ± 4.6
Systolic blood pressure (mm Hg)	125 ± 11	123 ± 13	121 ± 17
Diastolic blood pressure (mm Hg)	79 ± 9	82 ± 9	80 ± 10
Serum			
Total cholesterol (mg/dL)	241.2 ± 23.3	243.9 ± 15.5	242.0 ± 27.9
Triglyceride (mg/dL)	164.3 ± 44.9	170.6 ± 61.9	193.1 ± 60.0
HDL-C (mg/dL)	48.8 ± 16.1	46.4 ± 11.4	42.7 ± 9.2
LDL-C (mg/dL)	143.8 ± 26.0	154.4 ± 26.7	156.1 ± 33.6
Aspartate aminotransferase (U/L)	29.7 ± 12.1	24.9 ± 7.9	27.6 ± 7.4
Alanine aminotransferase (U/L)	29.9 ± 11.8	26.6 ± 8.3	27.7 ± 6.4
Blood urea nitrogen (mg/dL)	11.8 ± 2.7[b]	14.9 ± 3.5[a]	12.4 ± 3.1[ab]

Values are mean ± SD, $n = 14$.

[ab]Values in the same row with different superscripts are significantly different at $P < .05$.

SD, standard deviation; HDL-C, high-density lipoprotein–cholesterol; LDL-C, low-density lipoprotein–cholesterol.

Before the study, subjects were educated using food charts and a food exchange list. The nutrition composition of the 3-day dietary records was calculated using Nutritionist Professional software (E Kitchen Business Corporation), and the nutrient database was based on the Taiwan food composition table (Department of Health, 2009, www.doh.gov.tw/FoodAnalysis/ingredients.htm).

Statistical analysis

SAS 9.1.3 software was used to conduct the statistical analysis. Data were expressed using mean and standard deviation. Data were analyzed by one-way analysis of variance followed by inspection of all differences between pairs of means by Duncan's multiple-range test in basal data, different water treatment at same period and drinking water at various times. Food intakes between after and before experiments were analyzed by paired *t*-test. Correlations between serum Mg level and serum total cholesterol were tested by Pearson's correlation analysis. $P < .05$ was considered to be statistically significant.

RESULTS

Baseline characteristics of the subjects and 3-days food intake

Age, height, body weight, waist circumference, hip circumference, blood pressure, and liver functions were recorded before the experiment and no statistical differences were noted (Table 2). Although differences in renal function were shown among three groups, their BUN values were in the normal range (7–21 mg/dL), suggesting normal kidney function. The concentrations of cholesterol, HDL-C, LDL-C, and triacylglycerols in subjects showed no significant differences among the groups at beginning of experiment.

Table 3 shows the food intake 3 days before and 3 days after the experiment. No statistical differences were found in energy intake, carbohydrate, fat, protein, dietary fiber,

Table 3. Three-Day Records of Food Intake Before (0 Week) and After (6 Weeks) Experiment

	RO water			DSW			MCF-water		
	Before	*After*	P *value*	*Before*	*After*	P *value*	*Before*	*After*	P *value*
Energy (kcal/day)	1853 ± 458	1867 ± 331	0.889	1841 ± 403	1957 ± 331	0.202	1871 ± 375	1767 ± 343	0.368
Protein (g/day)	71.0 ± 18.3	67.5 ± 16.1	0.392	67.3 ± 21.0	71.3 ± 10.6	0.352	67.4 ± 17.8	64.5 ± 14.1	0.625
Fat (d/day)	71.1 ± 17.5	69.6 ± 14.3	0.733	66.3 ± 22.2	78.2 ± 20.1	0.065	73.1 ± 16.7	67.2 ± 8.2	0.254
Carbohydrate (g/day)	227 ± 55	241 ± 33	0.407	243 ± 45	240 ± 43	0.783	228 ± 56	217 ± 64	0.566
Fiber (g/day)	13.3 ± 8.6	13.9 ± 5.4	0.724	12.9 ± 4.4	12.8 ± 4.6	0.959	13.3 ± 5.5	12.1 ± 6.5	0.469
Vitamin A (μg RE/day)	957 ± 538	1104 ± 1054	0.653	1456 ± 1252	717 ± 553*	0.012	1248 ± 1225	1108 ± 842	0.635
Vitamin E (mg α-TE/day)	7.3 ± 3.0	11.4 ± 10.0	0.190	9.5 ± 5.8	8.8 ± 3.1	0.630	7.8 ± 3.0	9.4 ± 4.6	0.253
Vitamin B_1 (mg/day)	1.2 ± 0.8	1.0 ± 0.2	0.333	0.9 ± 0.3	0.9 ± 0.2	0.994	1.0 ± 0.6	0.9 ± 0.3	0.419
Vitamin B_2 (mg/day)	1.2 ± 0.8	1.2 ± 0.7	0.916	1.0 ± 0.5	1.0 ± 0.4	0.396	1.0 ± 0.3	0.9 ± 0.3	0.215
Vitamin B_6 (mg/day)	1.4 ± 0.6	1.3 ± 0.3	0.395	1.2 ± 0.5	1.2 ± 0.4	0.761	1.2 ± 0.4	1.2 ± 0.5	0.779
Vitamin B_{12} (μg/day)	4.8 ± 4.1	5.1 ± 5.3	0.826	4.9 ± 4.2	6.2 ± 4.5	0.395	5.3 ± 4.2	3.6 ± 2.2	0.244
Vitamin C (mg/day)	102 ± 43	108 ± 60	0.770	136 ± 99	103 ± 49	0.329	102 ± 61	119 ± 100	0.466
Sodium (mg/day)	1485 ± 759	1824 ± 1110	0.293	1462 ± 470	1824 ± 399*	0.033	1411 ± 728	1431 ± 895	0.945
Potassium (mg/day)	1850 ± 653	1725 ± 379	0.403	1853 ± 573	1697 ± 503	0.275	1759 ± 506	1587 ± 523	0.153
Calcium (mg/day)	482 ± 284	400 ± 231	0.087	428 ± 242	338 ± 164	0.102	360 ± 156	355 ± 116	0.153
Magnesium (mg/day)	203 ± 76	201 ± 45	0.877	202 ± 53	199 ± 39	0.820	218 ± 69	196 ± 73	0.127
Phosphorous (mg/day)	923 ± 275	889 ± 167	0.463	864 ± 231	875 ± 158	0.844	896 ± 267	862 ± 262	0.682
Iron (mg/day)	10.4 ± 3.6	10.4 ± 3.1	0.988	10.1 ± 2.6	10.4 ± 2.5	0.715	9.6 ± 2.4	8.5 ± 4.4	0.422
Zinc (mg/day)	8.1 ± 2.1	7.6 ± 2.0	0.316	7.9 ± 2.8	7.9 ± 1.9	0.976	7.8 ± 2.1	7.3 ± 1.7	0.521

Values are mean ± SD, $n = 14$.

*Significantly different from corresponding before group (pair *t*-test; $P < .05$).

vitamin E, or vitamins B_1, B_2, B_6, B_{12}, or C. Intake of minerals, such as K, Ca, Mg, iron, and zinc showed no differences before or after the experiment. Na intake was lower ($P=.033$) before the study in the DSW group, but no difference was found between RO and MCF groups.

Effects of DSW on serum and lipoprotein lipids

Compared with the level at week 0, serum total cholesterol of the DSW group showed a 7% and 13.7% decrease at weeks 3 and 6, respectively (Table 4), and this effect was progressively enhanced with time. In addition, there was a significant decrease in serum LDL-C level of 11.7% and 15.4% at weeks 3 and 6, respectively, compared with that of week 0. Further, total cholesterol levels of subjects in the DSW group were significantly lower than those of the MCF or RO groups, and the changes in LDL-C and HDL-C showed a similar pattern of change to that of total cholesterol. Compared with the ratio of LDL-C/HDL-C at week 0, a lower tendency was observed at weeks 3 and 6 in the DSW group. Drinking DSW had no significant effect on triacylglycerol levels. On the other hand, there showed no gender-dependent difference in serum or lipoprotein lipids.

Effects of DSW on serum minerals, liver and kidney functions, and blood pressure

No statistical differences were found in serum Mg, Na, K, and Ca levels in the DSW group during the experimental period (Table 5). There was no difference in serum Mg between the DSW and MCF groups. There was no evidence of deficiency or over-dosage of Mg; Mg concentration was within a normal range throughout the entire study. However, Mg levels at weeks 3 and 6 were higher than that of week 0 in DSW and MCF groups. Figure 1 shows the relationship between serum Mg and total cholesterol at weeks 0, 3, and 6. Although there was no significant correlation between Mg and cholesterol at those time points, Figure 1 shows an inverse tendency between the two factors at weeks 0 ($r=-0.26119$, $P=0.0948$) and 6 ($r=-0.26396$, $P=0.0912$).

Water types had no effect on the activities of AST and ALT. In addition, no statistical differences were observed in BUN and blood pressure during the experiment (data not shown).

Table 4. Effects of Deep Seawater on Serum and Lipoprotein Lipids at Weeks 0, 3, and 6

Parameters/ groups	*Week 0 (mg/dL)*	*Week 3 (mg/dL)*	*Week 6 (mg/dL)*
Total cholesterol			
RO water	241.2±23.3	235.0±25.3	239.9±33.4^{x}
DSW	243.9±15.5^{a}	224.7±17.3^{b}	210.4±17.1^{cy}
MCF-water	242.0±27.9	239.9±36.1	233.6±50.9^{xy}
LDL cholesterol			
RO water	143.8±26.0^{b}	140.9±25.4^{b}	154.6±33.4^{a}
DSW	154.4±26.7^{a}	136.4±23.4^{b}	130.6±22.3^{b}
MCF-water	156.1±33.6	152.4±31.1	144.1±43.8
HDL cholesterol			
RO water	48.8±16.1^{ab}	44.4±14.3^{b}	51.7±17.0^{ax}
DSW	46.4±11.4^{a}	42.9±11.3^{ab}	40.8±8.0^{by}
MCF-water	42.7±9.2^{ab}	39.2±6.5^{b}	45.0±13.0^{axy}
LDL-C/HDL-C			
RO water	3.28±1.33	3.44±1.06	3.26±1.09
DSW	3.59±1.28	3.42±1.12	3.29±0.77
MCF-water	3.84±1.24^{ab}	4.03±1.26^{a}	3.36±1.19^{b}
Triacylglycerols			
RO water	164.3±44.9	157.7±28.0^{xy}	171.1±47.1
DSW	170.6±61.9	149.9±29.5^{y}	165.9±38.5
MCF-water	193.1±60.0	176.0±31.4^{x}	177.4±34.5

Values are mean±SD, $n=14$.

^{abc}Values in the same row with different superscripts are significantly different at $P<.05$.

^{xy}Values in the same column with different superscripts are significantly different at $P<.05$.

Table 5. Concentrations of Magnesium, Sodium, Potassium, and Calcium in Serum at Weeks 0, 3, and 6

Parameter/groups	*Week 0*	*Week 3*	*Week 6*
Magnesium (mg/dL)			
RO water	2.06±0.14	2.01±0.17^{y}	2.07±0.16
DSW	2.05±0.12^{b}	2.15±0.14^{ax}	2.13±0.15^{ab}
MCF-water	2.15±0.14	2.21±0.12^{x}	2.07±0.26
Sodium (mEq/L)			
RO water	145.3±17.6^{y}	153.4±19.3	150.1±9.7^{x}
DSW	158.0±15.0^{x}	156.7±19.1	150.8±10.9^{x}
MCF-water	150.4±8.8^{axy}	148.5±10.0^{ab}	142.2±8.2^{by}
Potassium (mEq/L)			
RO water	3.90±0.48^{xy}	3.83±0.55	3.73±0.30
DSW	4.16±0.57^{x}	4.27±0.89	4.10±0.85
MCF-water	3.77±0.15^{y}	3.78±0.34	3.69±0.27
Calcium (mg/dL)			
RO water	8.88±0.80	8.99±0.52	9.14±0.77
DSW	8.97±0.80	9.18±0.36	9.20±0.69
MCF-water	8.92±0.61	9.04±0.50	8.94±0.36

Values are mean±SD, $n=14$.

^{ab}Values in the same row with different superscripts are significantly different at $P<.05$.

^{xy}Values in the same column with different superscripts are significantly different at $P<.05$.

Effects of DSW on serum antioxidant capacity and fat peroxidation

In the present study, we determined the state of oxygen stress by measuring serum TBARS values and total antioxidant capacity (TAC). The results indicated no significant differences among these three groups in serum TAC (Table 6). However, TBARS values were lower at weeks 3 and 6 than at week 0 in the DSW group.

DISCUSSION

At the beginning of the study, the average values of serum total cholesterol among the three groups were in the range of 241–244 mg/dL, and LDL-C was in the range of 143–156 mg/dL. According to the ATP III of NCEP (U.S.

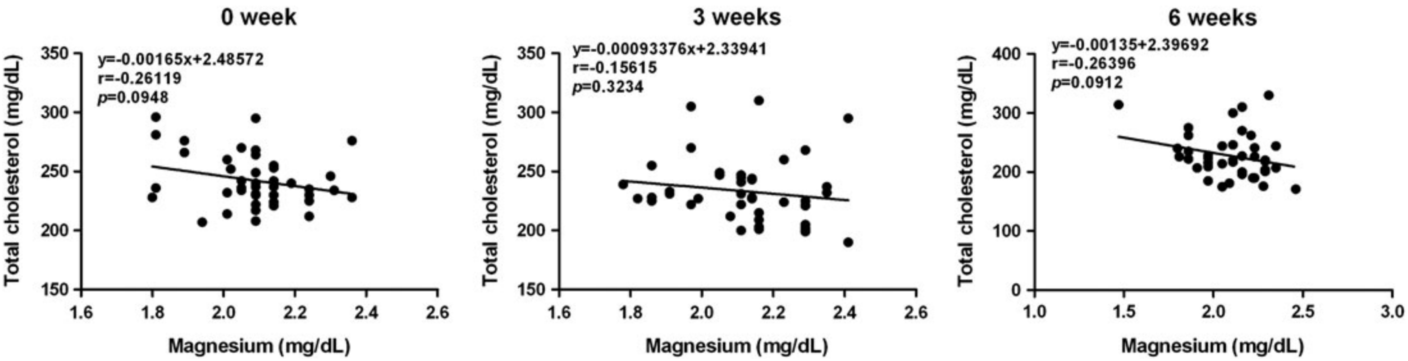

FIG. 1. Relationship between magnesium and total cholesterol concentration in serum at 0, 3rd, and 6th week ($n=42$).

National Cholesterol Education Program, 2001), subjects in this study had marginally high or high values of serum cholesterol and LDL-C, which therefore disposed them to a high risk of developing cardiovascular diseases. We found that the total blood cholesterol and LDL-C levels were reduced in hyperlipidemic subjects, and this reduction was proportional to the length of drinking time. These data were consistent with the results obtained from previous animal studies.[4,17] Further, Miyamura *et al.*[18] also found a decline of total cholesterol and LDL-C in rabbits fed a high cholesterol diet with DSW drinking for 12 weeks, and DSW was more effective than surface seawater in preventing atherosclerosis.

Although the mechanism of the cholesterol-lowering action of Mg is unknown, the hypocholesterolemic effects of DSW are thought to be the influence of minerals.[2,4,11] Rabbits fed a high cholesterol diet supplemented with Mg (36 mg/100 g) for 6 months were found to have a significant decrease in serum cholesterol with reduced cholesterol accumulation on artery walls, and increased lipid excretion in feces.[19] Vaskonen[20] proposed Ca and Mg might bind with fatty acids and bile acids in the small intestine, which then inhibits the absorption of saturated fatty acid, a mechanism which has also been demonstrated inhibit fat absorption.[10]

DSW is rich in minerals, and in our study the Mg concentration was 395 mg/L. Studies have indicated that Mg supplementation could potentially reduce total blood cholesterol[3] and prevent some kinds of cardiovascular disease, including atherosclerosis.[21,22] Intake of desalted DSW with high Mg improved lipid metabolism and was apparently capable of preventing atherosclerosis. Recently, Schoppen *et al.*[23] pointed out that drinking sodium bicarbonate–rich mineral waters could reduce postprandial lipemia in healthy postmenopausal women when compared to drinking low mineral content water. Moreover, these mineral rich waters improve lipid profile in moderately hypercholesterolemic young subjects and could be applied in dietary interventions to reduce cardiovascular risk.[24]

It is known that hardness of drinking water is related to cardiovascular diseases.[25] Yang *et al.*[26] indicated that there was a significant increase in mortality in ischemic cardiovascular disease if hardness of drinking water was below 150 ppm. The hardness of drinking water in the current study was 1410 ppm, and we assumed this would reduce the risk of cardiovascular diseases in our subjects. Mg was the major mineral in DSW used in this study, and Mg levels were 50 times higher than Ca levels. Based on the results of previous studies, it is reasonable to postulate that Mg levels have an inverse correlation with cardiovascular diseases.

However, there are many minerals and trace elements in DSW, such as sulfate, lithium, selenium, molybdenum, silicon, and zinc, etc. In the present study, a reduction of serum cholesterol concentration and TBARS level was observed only in subjects drinking DSW but not those drinking MCF water. However, serum Mg level was increased only at the 3rd week by drinking DSW. Thus, the Mg content in these types of water could not be a sole factor behind this effect. We therefore postulate that Mg was not the sole factor in reducing lipids, as other trace elements may also be involved. Further studies are warranted to further clarify the mechanism.

Our results showed that DSW was capable of significantly decreasing TBARS values. Similar results regarding

Table 6. Effects of Deep Seawater on Serum Trolox Equivalent Antioxidant Capacity and Thiobarbituric Acid-Reactive Substances at Weeks 0, 3, and 6

Parameter/groups	*Week 0*	*Week 3*	*Week 6*
Serum TEAC (mM)			
RO water	0.86 ± 0.05^{b}	1.04 ± 0.03^{ax}	1.04 ± 0.06^{ax}
DSW	0.84 ± 0.04^{c}	0.90 ± 0.03^{by}	1.02 ± 0.06^{axy}
MCF-water	0.86 ± 0.06^{c}	1.03 ± 0.08^{ax}	0.99 ± 0.05^{by}
Serum TBARS (nmol/mL)			
RO water	3.86 ± 0.86^{aby}	4.16 ± 1.10^{a}	3.42 ± 0.65^{by}
DSW	4.80 ± 0.93^{ax}	4.31 ± 0.72^{b}	4.07 ± 0.51^{bx}
MCF-water	3.75 ± 0.95^{by}	3.90 ± 0.97^{ab}	4.30 ± 1.05^{ax}

Values are mean ± SD, $n=14$.

[abc]Values in the same row with different superscripts are significantly different at $P<.05$.

[xy]Values in the same column with different superscripts are significantly different at $P<.05$.

TEAC, trolox equivalent antioxidant capacity.

antioxidative capacity of DSW was reported in male hamsters' serum and liver.[5] In another study, administration of DSW to rabbits fed a high cholesterol diet for 12 weeks resulted in lowering TBARS values.[18] The lower content of Mg in RO water might cause an oxidative stress, and the similar results were showed between TAC and Mg intake in healthy young adults.[27]

The food intake that was recorded for a 3-day period at the beginning and at the end of the study revealed no differences in intake of antioxidants (such as vitamin E, vitamin C, iron, zinc, etc.) between pre- and poststudy data. Therefore, any possible mechanism by which food intake could have reduced values of TBARS is unclear, which suggests that the lower values were caused by water consumption and not by factors related to food intake. Rayssiguier *et al*.[28] reported that Mg deficiency could enhance fat peroxidation in animal tissues and decrease antioxidants. Apparently, free radicals were involved in the process. Mg deficiency in rats increased blood TBARS values and free radicals generation.[29,30]

On the other hand, DSW utilized in the present study had higher sulfur salt content (167 mg/L) than that of the RO or MCF. Sulfur is a nonmetallic element, and comprises 0.25% of human body weight.[31] Sulfur is contained in methionine, cysteine, and taurine, and takes part in many enzyme reactions and is involved in protein synthesis. Recent research indicates that sulfur-containing molecules may play an important role in antioxidation, and are involved in oxidative stress caused by aging and age-related disorders.[32,33]

CONCLUSIONS

In conclusion, we have confirmed the null hypothesis that DSW was effective in significantly reducing serum total cholesterol and LDL-C in hypercholesterolemic subjects, and these hypocholesterolemic effects progressively increased with duration of DSW administration. DSW also lowered serum TBARS values in hyperlipidemic subjects. There was a tendency of reverse correlation between serum Mg and cholesterol concentration. The other trace elements in DSW may be involved in the overall lipid-lowering effects, and further studies are warranted to elucidate the underlying mechanisms.

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AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

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