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Health effects of long term consumption of water low in calcium, magnesium or TDS: studies from Eastern Europe

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Introduction

The relationship between the consumption of soft or low mineralized water and the incidence of some diseases has been discussed in literature since the 1960's. Some of the recent reviews agree that regular consumption of such water poses a health risk. Nevertheless, critics found some weak points, e.g. the English language bias, as most reviews only included publications in English. This contribution intends to show that in Central and Eastern Europe, multiple authors paid attention to this issue and a lot of studies that have significantly supplemented existing knowledge have been available in several national languages. One of the reasons why desalinisation has, from the very beginning, been considered not only a technical but also public health problem could well be the national methods of managing water supplies. Such surveillance was conducted in the former USSR and other European communist satellites by the Public Health Service; in other words, by medically educated personnel.

In the former USSR, the first cue to possible health risks from low mineralized water was provided in the mid 20th century by negative empirical experience gained with the consumption of water from melted snow during polar and climbing expeditions and of distilled water prepared on transoceanic ships. Other challenges were the need for drinking water supplies in developing regions with a lack of fresh water particularly in Central Asia and the search for water regeneration and recycling during long-term space flights. For instance, in 1974 the USSR had over 100 desalination units based on electrodyalisis (Sidorenko, 1974) as well as a nuclear distillation facility supplying water to over 100 000 inhabitants (Shtannikov, 1975) in the Kazakhstan town of Schevtshenko where the majority of medical research was conducted. Medical research focused on two aspects: 1) health effects of demineralised water, 2) minimal or optimal concentrations of total dissolved solids (TDS) and selected essential elements that are vital in remineralized water.

The overwhelming majority of the Eastern European articles are in Russian due to the fact that the majority of experiments were conducted in Russia and because Russian journals published articles by foreign authors.

Method

Since the Internet search engines and current medical literature databases are of limited use for retrieval from older Russian articles, we used the following approach: the key Russian scientific journal in the area of public and environmental health "Гигиена и санитария" (Hygiene and Sanitation) from 1965 to 2005 was searched manually. The references of the retrieved articles were then checked for further relevant articles and based on the authors' names; the PubMed database was searched for links from other journals. More than 100

publications were yielded this way, comprising ‘water desalinasation’, ‘soft water’ ‘water regeneration’ etc. Unfortunately, a number of studies were published in various collections of abstracts or monographs which are unavailable via inter-library loans. From this number we excluded the unavailable articles and those dealing with safety and technical issues such as suitable methods for desalinated water remineralization, testing the safety of materials and chemicals, microbiological stability of desalinated water, and presence of toxic substances etc.
As a result, 43 original research articles on the health effects of drinking water were reviewed: 15 experimental and epidemiological studies on humans, 25 experimental studies on animals (rats, dogs, rabbits, cats) and 3 studies using the same or similar experiment design for both humans and animals. With the exception of a Bulgarian article, all of these were by Soviet or Russian authors. Four additional articles originated from the former Czechoslovakia and were in Czech, Slovak and German; one Serbian study was retrieved.

Results
The reviewed articles can be thematically divided into several groups. The largest group (27 studies) comprises studies of the health risks of desalinated water and the scientific justification of minimal or optimal mineral content of remineralized (conditioned) drinking water.

Schevtshenko Studies
The primary basis for the USSR recommendations about mineral content were results of large-scale systematic research conducted between 1968 – 1975 at what was then the largest Soviet desalination facility in Schevtshenko (now known as Aktau, Kazakhstan Republic). Drinking water here was provided by distillation of sea-water from the Caspian Sea, and the distillate was mixed with highly mineralized ground water high in sulphate, chloride and sodium compounds. Low calcium content was typical. Research comprised epidemiological studies as well as interventional and experimental human studies of several health markers: examination of blood and tissue, kidney, gastrointestinal and cardiac function including various load tests (Bokina, 1978). For the purposes of confirming findings and quantification of recorded influences, animal experiments were likewise performed.

A series of clinical tests performed on healthy volunteers aged around 20 years of age focused on detecting the minimum mineralization rate that might cause pathological changes. Each series of tests monitored 20 to 60 subjects who received standard diet and water with varying TDS values (water distilled over TDS 1000 mg/l) and who were precisely measured for intake and output of the major electrolytes. Consistent findings revealed elevated excretion of sodium in persons receiving water of TDS ≤ 50 mg/l. The concentration of sodium in blood plasma of these persons was also significantly increased ($p < 0.05 – 0.01$) and this increase was accompanied by increase of blood plasma volume and by a decrease in the volume of extracellular fluid (Rozval, 1971; Bokina, 1975a; Grischelevich, 1975; Rakhmanin, 1975; Sergeyev, 1982). These findings were supported by the results of accompanying animal experiments (Rakhmanin, 1975; Sergeyev, 1982).

The influence of desalinated water on the state of gastric or duodenal mucosa was studied via cohort studies of children and adults who resided for various time-periods in Schevtshenko and Moscow (control group). Whilst in children the enterokinase and acidic phosphatase concentrations were not statistically different, adults who had resided in Schevtshenko for over two years had twice the incidence of hypoacidity compared to residents of less than one year or persons who resided in Moscow (Bokina, 1973). A tendency of hypoacidity among the Schevtshenko population (residents for over five years) was revealed by the examination of 120 healthy subjects (Sidorenko, 1971).

The influence of desalinated water with low calcium content on the phosphorous and calcium metabolism was studied in children and adults. Persons who had resided in Schevtshenko for more than five years had less favourable phosphorous and ALP values as well as elevated skin capillary permeability, although the results were not statistically significant (Pribytkov, 1972). Further studies (2700 subjects) revealed that persons who had resided for more than five years had decreased levels of calcium, phosphorous and alkaline phosphotase. In the case of residency exceeding five years, a decrease of minerals in bone structure was also observed (Bokina, 1975a). A load tests with varying doses of calcium lactate in children (500 subjects) from Schevtshenko and Moscow showed that children with long-term consumption of desalinated water had elevated excretion of calcium (Bokina, 1976). This finding is similar to findings from studies of rats consuming distilled water; the animal studies also reported negative effects on skeletal calcification levels (Bokina, 1975b).

Long-term (i.e. up to 15 months) consumption of desalinated sea water did not influence the chromosomal system of human body cells in blood donors (Rakhmanin, 1980).

Other Animal Studies in the Former USSR

Alongside research stemming from studies in Schevtshenko there is significant group of chronic and sub-chronic animal experiments. The primary reason for these studies was to provide information about adequate levels of mineralization of desalinated water in space and transoceanic ships, as well as the municipal applications. In several studies, conducted under standard conditions, experimental animals received water with various TDS; tests usually considered a broad spectrum of markers. In general, the studies fairly consistently showed the negative effects of distilled water or water with a low content of dissolved substances (TDS < 100 mg/l) on certain followed metabolic parameters and ratio of certain electrolytes (chlorides, sodium, calcium) and lipids, diuresis, gonad function, embryonic development and the morphology and mass of internal organs (Elpiner, 1969, 1980; Shafirov, 1973; Parkhomchuk, 1974; Balashov, 1982; Rakhmanin, 1982, 1989a, 1990; Kuzanova, 1990). Two studies did not find negative effects. One focused on only the effects on nucleic acids content and the activity of nucleases in various bodily organs (Kulikova, 1977). The other study considered only one type of medium remineralised water (Strikalenko, 1988).

An interesting adjunct comprises rat animal studies concerning minimal and maximum acceptable values of sodium and potassium values in regenerated drinking water. This concerns haemeopoiesis, cardiac function, morphology and liver function, metabolic activity of selected electrolytes, enzyme and hormonal activity, total body and organ mass etc. The investigators concluded that sodium concentration in water of approximately 5 – 35 (50) mg/l and potassium from 1 – 5 mg/l had minimal negative effects on experimental animals (Omelyanec, 1984; Kondratyuk, 1985, 1988a, 1988b). Kondratyuk (1989) studied the beneficial effects of other elements in rats (I, Co, Mn, Cu, Mo, Zn, F) induced by water of varying mineralization and found that low-mineralized water enriched with elements investigated had positive effects on blood formation and on the concentration of the microelements in muscles and liver.

Two animal studies focused on the effects of various calcium concentrations in water. The Ca content in drinking water up to 100 mg/l has led to effective utilization of this element in organism of cats (particularly bones and blood). However, with high Ca levels (100 – 500 mg/l) the interchange of Ca in bones is considerably slowed down, and this can manifest in an increased or excessive calcification of bone tissues (Basmadzhieva-Tancheva, 1965). A study conducted by Kondratyuk (1982) is hard to interpret, because one out of two groups of experimental rats has an inadequately defined water quality.

Epidemiologic Studies in the Former USSR

A further significant group of studies (7 articles including two discussion parts) comprises cross sectional epidemiological studies with varying water hardness under actual conditions. Levin et al. (1981) and Novikov et al. (1983a) investigated the changes in selected physiological functions (neural, cardiovascular, biochemical) in two cohorts of women living in regions with drinking water of different hardness. Levin studied 460 women in four unspecified areas similar in climatic, geographical, social-hygienic, and industrial aspects but with differing water quality (Table 1). Novikov studied women in four regions of southern Siberia with the same geographical and climactic conditions and same levels of social and communal services, nutritional conditions and traditions. A questionnaire survey helped Novikov select a cohort that consumed similar amounts of milk, meat, vegetables and fruit.

Table 1. Minerals in drinking water in Levin et al. study.

Parameters (mg/l)	**Region A**	**Region B**	**Region C**	**Region D**
Calcium	3.0	18.0	22.0	45.0
Magnesium	2.4	5.0	11.3	26.2
Sulphate	6.0	12.0	8.0	30.0
Chloride	6.0	8.0	12.0	10.0
TDS	146.2	176.2	68.3	225.2

Novikov selected 511 women employees from preventive medicine, child, or pre-school facilities. The women were 20 to 49 years of age and had children and no chronic illness. The women did not work under unfavourable conditions and had lived in the same region for more than 10 years. The regions differed in drinking water quality. Based upon the reported concentrations of Ca and Mg in the drinking water, it appears that the regions were the same as those studied by Levin et al.

Unlike other studies that considered only the occurrence of disease or certain pathologies, the above mentioned studies considered early physiological changes that can precede overt disease. These two studies found that women living in cities with the lowest levels of Ca and Mg more frequently had cardiovascular changes as measured by ECG, higher blood pressure, somatoform autonomic dysfunctions, headache, dizziness, and osteoporosis compared to women in cities with harder water. Novikov found similar results in an experimental study with laboratory rats testing similar concentrations of Mg and Ca added to drinking water. Five groups of animals were exposed to five different concentrations of Mg and Ca in their drinking water (3&4, 3&24, 10&20, 10&12, 30&40 mg/l). The results of the experimental and epidemiological studies lead Novikov to recommend a minimum concentration of these minerals in drinking water: at least 10 mg/l of Mg and 20 mg/l of Ca.

In another article, Novikov et al. (1980) presented the results of morbidity comparison in two areas of the Far East. Water in the investigated area has a low mineral content (TDS 50 – 70 mg/l), low hardness (0.8 – 2.0 mg-eq/l[1]), low calcium content (2.0 – 15.0 mg/l), low magnesium content (2.0 – 10.0 mg/l), a lack of fluoride (0.2 – 0.3 mg/l). At the same time, the water contains ions of lead, arsenic, cobalt, silver, selenium, molybdenum and – although

[1] mg-eq/L – hardness units; 1 mg-eq/L = 0.5 mmol/L (∑ Ca + Mg)

none of these elements exceed its respective standard limit value – the sum of ratios of each of these substances towards the respective standard value represents 1.6 – 2 multiple of maximum acceptable concentration. This area was very similar to the control one (as for climate, industry, ecology etc.); the only significant differences were in above mentioned water parameters. The quality of water in the control area corresponds to the hygienic requirements: total hardness 4.5 – 4.2 mg-eq/l, calcium 33 – 47 mg/l, magnesium 20 – 25 mg/l, chloride 90 – 110 mg/l, sulphate 21 – 30.4 mg/l, zinc 0.01 – 0.02 mg/l, fluoride 0.4 – 0.7 mg/l. No manganese, lead, arsenic, silver, molybdenum and selenium were found out in the control water.

Novikov et al investigated health status of population in both chosen areas (in children, youth and women at the age of 20 – 55 not being employed in plants with unfavourable working conditions). Only persons without congenital pathologies and traumas, living in respective areas at least 5 years, with satisfying living conditions, without harmful habits (e.g. alcohol, abuse etc.) and regularly consuming milk and meat products were chosen for the study. The morbidity evaluation was conducted with help of registers and questionnaires. At the same time, medical follow-ups were accomplished. In the investigated area, statistically significant differences (in terms of less favourable results) in following parameters were found out: relative number of visits at GP in children (1 - 14 years) and youth (14 – 17 years); morbidity rate regarding endocrine system diseases and nourishment disorders; morbidity rate of nervous system and sense organs diseases; morbidity rate of digestive tract diseases; bone and muscle system diseases.

After the analysis, women living in the respective area at least 20 years and consuming water of investigated quality, having children, living under sufficient living conditions, without harmful habits and regularly consuming milk and meat products were chosen for medical follow-ups. In total, 166 women in the investigated area and 125 women in a control area were chosen. General follow-ups showed that following diseases are more often in the investigated area in comparison with the control one: chronic pyelonephritis; urolithiasis, chronic cholecystitis; chronic colitis; chronic gastritis; chronic ischemic heart disease; hypertension; in 20,1 % persons osteoporosis (in the control area in 10,6 %) and cystoid clearing in radiocarpal joints and phalanges were x-rayed.

The described human research was completed by experimental verification of the results in 10 month experiments on white rats, in which natural conditions of water consumption were simulated. The obtained data give additional evidence of certain changes in experimental animals in comparison with the control ones.

In a further article where Novikov et al. (1983 b) employed the same methodology, they reported other results from their research in the Far East on the population health of approximately 8000 persons, some of which underwent questionnaire research and detailed medical examinations. The results of the research show that in areas with soft drinking water (water hardness < 1.6 mg-eq/l, Ca < 30 mg/l, Mg < 10 mg/l) there was a statistically higher number of persons in “risk zone” of blood pressure, with lowered QRS voltage, chamber arrhythmia, changes in the mucous membrane of the tongue painful stomach and liver on palpation, with X-ray signs of gastritis and osteoporosis. There was also a higher occurrence of astheno-vegetative syndromes, headaches and vertigo.

The previous article by Novikov et al. (1980) was criticised by Arkhipov (1982), who, among other things, pointed out that the nutritional factor – easily explaining the Ca and Mg water-intake differences – was inadequately explored. The authors replied (Novikov, 1983c) by stressing the importance of the presence of both elements in drinking water, for example its easily absorbable ionic form or substantial losses of all essential elements from food when cooked in soft water, but otherwise they did not mention the question of quantification of individual nutritional intake of the elements.

Lutai (1992) studied the relationship between the content of TDS, hydrogen carbonate, hardness, chloride and sulfate in drinking water and the health of the population in southern Siberia. Included in the study were 14 settlements and other areas on the right and left bank of the river Angara supplied with water of different mineral composition (Table 2).

Table 2. Minerals in drinking water in Lutai study.

Parameters (mg/L)	**Region I**	**Region II**
Bicarbonates	86.4 ± 0.7	242.7 ± 4.1
Calcium	18.7 ± 0.5	28.5 ± 2.4
Magnesium	4.9 ± 0.3	8.3 ± 0.5
Chlorides	5.5 ± 0.2	15.2 ± 1.2
Sulfates	10.8 ± 0.3	44.6 ± 3.2
Potassium + Sodium	7.2 ± 0.3	55.8 ± 4.6
TDS	133.5 ± 1.2	385.2 ±11.9

The Lutai study found adverse health, reproductive and developmental effects among the population of Region I, and the results suggest that drinking water with a low TDS and low bicarbonates may unfavorably affect the physical development of children and reproductive health of women and may be responsible for some pathologies in newborns. Region I also had a more frequent occurrence of simple goiter, thyreotoxicosis, hypertension, ischemic heart disease, gastric and duodenal ulcers, chronic gastritis, cholecystitis, and nephritis, and water quality was correlated with endemic disease risks and cardiovascular and gastrointestinal pathology. All of the water constituents that were studied were correlated with some of the health-related parameters and disease, but bicarbonates had the greatest number of correlations. Lutai concluded that a low content of bicarbonate in drinking water can play an important role in incidence of some diseases and recommended the following as optimal mineral concentrations in drinking water: 250 – 500 mg/l bicarbonates; 400 mg/l of TDS; 60 mg/l of Ca; and 26 mg/l Mg.

For the sake of completeness, we also reviewed several ecological epidemiological studies, albeit that their significance is limited.
An ecological study by Livshits et al. (1975) in 18 districts of the Minsk region and 16 districts in Brest region provides support for an inverse association with malignant tumours. Livshits et al. found weak negative correlations between the hardness of water and the incidence of kidney malignant neoplasms ($r = 0.4$, $p = 0.05$) and urinary bladder malignant neoplasms ($r = 0.46$, $p = 0.01$).
Anan´ev (1987) investigated the influence of low concentrations of ten microelements in drinking water on morbidity of the population from cardiovascular diseases in 10 rural areas with approximately same natural, climatic and demographical conditions were collected and processed. The study shows that there is a correlation between the elements occurring in drinking water and the morbidity from cardiovascular diseases. As regards manganese, chromium, vanadium, molybdenum, silver, zinc and bromide, the correlation was negative and it can be supposed that low concentrations of these elements in drinking water have a protective function, whereas the correlation between copper and titanium and these diseases was positive.

Epidemiologic Studies in the Former Czechoslovakia and Serbia
Four more articles originated from former Czechoslovakia (Svec 1975; Svec 1976; Birova 1985; Kubis 1985) and were in Czech, Slovak and German and one Serbian study

(Maksimovic, 1998) was retrieved. These are all ecological epidemiological studies which add to the number of countries where an inverse relationship was found between the water hardness and occurrence of cardiovascular or cerebrovascular diseases.

Other Studies

The last group of articles provides further evidence of the protective effects of calcium and magnesium ions in drinking water against the toxic effects of certain elements (strontium-90, arsenic, aluminium and selenium), or their cumulative effects (Sr-90). One article reported a real-time study on humans (Sukhomlina, 1971), the other cases involved animal experiments (Knizhnikov, 1968; Novikov, 1985; Tulakina, 1987, 1988; Plitman, 1989). Increasing water hardness correlated with increasing NOEL and LOAEL values in the elements studied. Similar prophylactic effects of calcium in diet against lead toxicity are described by Sukhanov et al. (1990).

Recommendations for the Mineral Content of Drinking Water

The results of the above-mentioned studies lead Soviet public health experts to express their opinion regarding the mineral composition of desalinated water (Rakhmanin 1989b). The above recommendation was based primarily on health effects, not technical aspects. The recommended mineral content is summarised in Table 3.

Table 3: Recommended contents of selected minerals in desalinated water.

Parameter	**Unit**	**Recommended values**
Total dissolved solids	mg/l	100 - 1000
Total hardness	mg-eq/l	1.5 – 7.0
Alkalinity	mg-eq/l	0.5 – 7.0
Calcium	mg/l	30 - 200 (ideally 50 - 75)
Magnesium	mg/l	10 - 50
Sodium + potassium	mg/l	≤ 200
Chloride	mg/l	≤ 350
Sulphate	mg/l	≤ 250
Bicarbonates	mg/l	30 - 420
pH		6 - 9

Note on hardness unit: 1 mg-eq/l = 0,5 mmol/l.
Note on alkalinity unit: 1 mg-eq/l = 0,5 mmol/l $CaCO_3$ = 50 mg/l $CaCO_3$.

Discussion

The reviewed Russian-language articles, describing the influence of desalinated water on health, represent unique research that has practically no parallel in the English-language literature.

Generally, it seems that the research was carefully conducted, but the reader may in some cases question the research methods because of the way in which results are often presented. Frequently, results are not clearly presented (i.e., text description instead of arrangement of data in tables), and in some cases, detailed information (e.g. on water quality) is not reported and appears incomplete. It is possible that the quantitative data may be available but just have not been reported in the article. One may object that some of these studies may not meet the current methodological criteria. However, we should not dismiss their findings and conclusions for the following reasons:

a) The human intervention studies would hardly be scientifically, financially or even ethically feasible to the same extent nowadays. The methods, however, are not so questionable as to make their results not valid. If not all conclusions, at least a number of partial information seem to be very useful and substantial.
b) Another studies have not yet been conducted that suggest different conclusions. Although reports have criticized the conclusions of Russian studies, they provided no scientific evidence to support their conclusion that consumption of water low in TDS was completely safe (WQA 1993).
c) Older Russian animal and clinical studies on health risks from drinking demineralised or low-mineral water yielded consistent results both with each other and with more recent research.

Regarding the publication bias, it would appear that this has not played a significant role. Some of the Russian articles reviewed have not revealed a relationship between given variables, but in the main there was the usual large quantity of monitored markers and associated relationships, which often led to the discovery of at least several correlations. This has given the authors the feeling that their research was worthwhile, and that the results should be published.

Conclusions

The studies reviewed strongly support the interim conclusion that demineralised water or low-mineral water – in the light of the absence or substantial lack of essential minerals in it – does not have the characteristics of safe drinking water, and therefore, its regular consumption or consumption in larger quantities should be considered as a potential health risk.

The published results reviewed here deserve to be published in the form of extended abstracts and an overview article or report in order to make these results available to scientists who can only read English-language articles. This would allow the research to be part of an overall evaluation of the literature on this subject. Moreover, there are still some additional references to another interesting original Russian research dealing with the relationship between health and mineral composition of drinking water, but these references (mostly the proceedings or monographies) remain inaccesible through standard library services to the reviewer. These also deserve to be found, evaluated, summarized, and made available to English-language readers.

P.S.

Three additional recent Polish studies were identified only after the symposium:

a) Drobnik M. (2002). Evaluation of the effect of deionized water on selected components of fat, carbohydrate, and protein metabolism, morphology and the acid-base equilibrium in the rats blood. (In Polish.) Roczniky Panstwowego Zakladu Higieny (Roczn. PHZ), 53(1), 27-32.
b) Drobnik M., Latour T. (2002). Effect of deionized water on the health status of population. (In Polish.) Roczn. PHZ, 53(2), 187-195.
c) Drobnik M., Latour T. (2005). Estimation of the influence of deionized water on the basic electrolytes level in blood and urine of tested animals. (In Polish.) Roczn. PHZ, 56(3), 283-289.

These papers are not reviewed here, but will be included in special paper which is prepared for publication.

P.P.S.

Detailed English abstracts of all reviewed papers will be available by the end of 2006 on: www.szu.cz/chzp/voda.

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