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총 설

Human Health Effects due to Consumption of Low TDS Water

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1. Introduction

Probably over most of recorded time, the quality of drinking water has been praised for good health and blamed for bad health. Certainly it is true, considering pathogenic organism that cause typhoid fever, giardiasis, etc., or considering chemical contaminants suspected of causing cancer.

Drinking "natural" waters with a high mineral content is generally accepted to be healthy. Water containing very low levels of total dissolved solids (TDS), such as distilled water, is believed by some to help "cure" arthritis by "washing out" calcium from deposits in joints. Along with this reasoning, many believe that drinking very low TDS water, treated by distillation, reverse osmosis (RO) or deionization (DI), "leaches" minerals from the body and causes mineral deficiencies with subsequent ill health effects.

The major driving force in the consumer marketplace for drinking water treatment equipment, including point-of-use, water vending machines and bottled water, is the organoleptic properties(taste, odor, color) and also safety from perceived dangerous levels of microbiological and chemical contaminants. Processes that are utilized by this equipment can reduce chemical contaminants effectively but also will produce a very low TDS drinking water. These processes included RO, DI and distillation. It is important to be assured that the treatment of drinking water by these processes do not cause ill health.

There are two mineral related issues involving low TDS in drinking water :

- Low TDS drinking water and mineral balance for dietary considerations.
- Low TDS drinking water causing leaching of minerals from body tissues leading to ill health.

The first issues have been addressed over the past several years on a worldwide basis and the general consensus is that drinking water should not be considered a dependable source of minerals such as calcium. This paper addresses the second issue only and attempts to answer the question, "Does consuming low TDS drinking water cause mineral and electrolytes to leach from body tissues and subsequently cause ill health?"

Table 1. Average Daily Water Balance

Daily Intake (ml)		Daily Loss (ml)	
Water, beverages	1500	Urine	1400
Metabolic	200	Skin	350
Food	600	Respiration	350
		Sweat	100
		Feces	100
Total	2300	Total	2300

Three areas leading to the answer to the above question will be addressed :

- The human body's own control mechanism, homeostasis.
- The 1980 unofficial World Health Organization (WHO) guidelines based on Russian studies that lead to a recommendation of 100mg/ℓ TDS as a lower limit for drinking water.
- Actual community experience with consumption of low TDS drinking water.

2. Natural Mineral Balance in the Human Body

The total amount of water in the body of a 70kg person is 40 liters. This amount includes 25 liters of water inside the cells (intracellular water) and 15 liter of water outside the cells (extracellular water). The average water balance under normal conditions at 20℃ is given in Table 1[1].

Under prolonged heavy exercise conditions, the daily sweat loss increase to 5000ml, respiration to 650ml and the daily urine volume decreases to 500ml with the total average daily water loss of 6600ml and the daily urine volume decreases to 500ml with the total daily water loss of 6600ml.

The severe volume and salt losses experienced from prolonged heavy exercise and/or high thermal exposure are best replaced with a water composition more closely aligned with the body's extracellular fluid. Salt water absorbed from the gut is held longer in the vascular compartment than pure water alone. It is consumption more promptly alleviates the signs of severe volume depletion. This is not a normal condition for most individuals in their daily consumption of drinking water. Thus normal conditions (not prolonged exercise and/or unusually high temperatures) are most appropriate for this study on the effects of low TDS drinking water consumption.

2. 1. Homeostasis

Homeostasis is the maintenance of static or constant conditions in the internal human body environment. This natural process controls the mineral and water concentrations in the body fluids within narrow limits inside and outside all the cells in all the organs and tissues in the human body. The following discussion is based on a major up-to-date physical text[1].

In homeostasis the body fluids involved include both extracellular (plasma and interstitial) and intracellular fluids. The concentration of sodium ions is highest outside the cell walls (approximately 10 fold of that inside the cell) and the concentration of potassium ions is highest inside the cell (approximately 15 fold of that outside the cell).

The total concentration of all the solutes is expressed as milliosmoles per liter (mOsm/ℓ) which relates to the osmotic pressure that drives water through the semipermeable cell walls. The osmolarity of these body fluids at equilibrium is 300mOsm/ℓ.

When the concentration of solutes is high on one side of thee cell wall and low on the other side, water moves across the cell wall from the low solute concentration side to the solute concentration side in order to equalize the osmotic pressure (osmosis). Any change from the normal concentration inside or outside the cell is corrected in one minute or less due to rate of water transport through the cell walls. About 30minutes is necessary for the whole body to be brought to equilibrium.

If normal drinking water averages about 300mg/ℓ TDS, then the average osmolarity of this drinking water is 10mOsm/ℓ (calculater as NaCl). This normal drinking water osmolarity is far from body

fluid equilibrium osmolarity of 300mOsm/ℓ. Water of very low TDS (<100mg/ℓ and <3mOsm/ℓ) is thus not very different from normal drinking water when considering its difference from normal body fluid TDS.

Textbook physiological calculations show that if one liter of water at zero mOsm/ℓ were injected into the extracellular fluid, the osmolarity would decrease to 293mOsm/ℓ, within the homeostatic limits; at two liters it would be 286mOsm/ℓ.

The kidneys control the overall concentrations of the constituents of body fluids. They filter about 180 liters of water per day but over 99% is reabsorbed. Only 1.0 to 1.5 liters are eliminated as urine under normal conditions. If the osmolarity of the fluid to be filtered by the kidney is lower than normal(low solute concentration), nervous and hormonal feedback mechanisms assist the kidney to excrete water at a lower osmolarity and thus raise the solute concentration in the body fluid to normal values. The opposite is true if the solute concentration of the fluid to be filtered is higher than normal.

The homeostatic mechanism in the kidney thus keeps the body fluids at the normal osmolarity value of 300mOsm/ℓ.

The osmolarity of the fluid to be filtered by the kidney is controlled to ±3% to maintain it at the normal level of 300mOsm/ℓ. The three basic nervous and hormonal control systems triggered by abnormal solute concentration in the body fluids to filtered by the kidney are anti diuretic hormone (ADH) from the pituitary gland, aldosterone from the adrenal cortex in the brain and thirst also from the brain. An osmolarity rise of about 1% causes thirst.

Osmoreceptors in the brain control the release of ADH(also called vasopressin). ADH is excreted when the plasma is too concentrated and causes the reabsorption of water producing a more concentrated excretion of solutes to decrease the plasma osmolarity. The resulting urine thus has an increased osmolarity being more concentrated in mineral salts. Aldosterone is secreted when the sodium concentration is low in the plasma and causes sodium to be reabsorbed, thus producing a more diluted urine. These control mechanisms keep the sodium concentration at ±3% and the potassium concentration at ±7%. Calcium secretion is controlled by parathyroid hormone to ± a few percent in the extracellular body fluid.

Water diuresis occurs when consuming large amounts of water (water loading). For example, in one case, a person drinking one liter of water caused the urine output to increase eight times after about 45 minutes and continue for two hours. Again the concentrations of solutes in the blood and other body fluids are quickly maintained by the kidney through homeostasis.

Thus, for a normal person, consumption of very low TDS water would not cause mineral depletion due to the homeostasis mechanism in the human body.

2. 2. Internal Body Secretions

Saliva increases the TDS of drinking water when it is consumed. An average of 800 to 1500mℓ of saliva are secreted per day by a normal person. The concentration of sodium chloride in saliva is 15 meq/ℓ or 877mg/ℓ; that of potassium ion is 30 meq/ℓ or 1170mg/ℓ; and that of bicarbonate ion 50~70 meq/ℓ or 3050~4270mg/ℓ. As low TDS water is consumed, it is combined with saliva which increases the TDS before it is absorbed in the gut.

Gastric and intestinal secretions also would help increase the TDS of drinking water when consumed. In the stomach, when stimulated (e.g. distention), the hydrochloric acid concentration can be as high as 5600mg/ℓ while potassium chloride and sodium chloride concentrations are 1120mg/ℓ and 175mg/ℓ respectively. Gastric secretions amount to an average of 1500mℓ/day in a normal person. Secretions in the small intestine average 1800mℓ/day and are almost pure extracellular fluid(300mOsm/ℓ).

Considering these internal body secretions, it is highly unlikely that, if low TDS water is consumed, the water absorbing through the gut will remain at

the low original TDS in a normal person under normal conditions.

Thus, based on the above highly credible and up-to-date textbook knowledge[1], it is difficult to believe that consumption of low TDS water by a normal person under normal conditions would cause unhealthy symptoms. [Normal person means free of diseases affecting the kidneys, hormone balance, etc.].

3. Unofficial WHO Guidelines

3. 1. WHO Publication

In 1980 WHO published an unofficial document entitled "Guidelines on Health Aspects of Water Desalination"[2]. This review was based almost entirely on publications by Russian authors. Another review was published by Sidorenko et.al.[3].

In these studies dogs, rats, rabbits and human volunteers were used. The drinking water used for these subjects was distillate and reconstituted distillate of chlorides, sulfates and bicarbonates ranging from 50mg/ℓ to 4000mg/ℓ. The distillate TDS was not given. The animals and humans were given standardized diets apparently adequate in all nutrients. Some of the animals were sacrificed after the test period and the tissues analyzed. The human volunteers were tested under desert and heavy exercise conditions and also under water loading.

The conclusion of these studies was that drinking water should contain no less than 100mg/ℓ TDS. It was claimed that consuming drinking water containing less than 100mg/ℓ caused :

- Reduced thirst quenching capacity.
- Increased consumption and diuresis.
- Leaching of minerals (sodium, potassium, chloride, calcium and magnesium) in the urine.
- Destructive physiological changes in the cells of the gut.

3. 2. Analysis

The first series of studies were carried out on rats and human volunteers concerning diuresis and leaching. The analysis is summarized bellow :

- An increase in diuresis was reported and certainly would be expected because water loading was used : "Volhards method" was indicated but not referenced. Standard water loading involves the consumption of 20mℓ per kg of body weight within about one hour (1400mℓ for a 70kg person)[4]. Water loading does not relate to normal water consumption conditions and thus is an inappropriate methodology.
- There were no hard numbers given for leaching, only a vague percentage of the "amount received" (undefined). It was reported that, among the other minerals, sodium was leaching into the urine. It was also reported that at the same time the sodium level was increased in the blood serum. Dietary sodium was not given.
- Although distillate, 100mg/ℓ TDS and 1000mg/ℓ TDS waters were reported to give essentially the same leaching and diuresis results, it was concluded that distillate provided greater leaching/diuresis levels particularly in water loading experiments.

These studies are not scientifically credible for consuming water under normal conditions due to conclusions based on inconclusive and vague data, and inappropriate water loading methodology.

Another set of human studies were carried out under severe water loss conditions : marching under desert conditions. Although the objective was not stated, it appeared that the investigators were trying to show that less volume of higher TDS water (distilled to 3000~4000mg/ℓ TDS) was required to slake the thirst of the volunteers compared to low TDS water. This might be expected under these conditions except that the composition of the waters were not close to that of extracellular fluid.

The reported results were inconclusive in that the volumes consumed did not show any pattern. For example, in one of the studies, the volume con-

sumed for distillate and 3000mg/ℓ TDS water was 1194mℓ and 1050mℓ, respectively. For 200mg/ℓ TDS water the consumption was 1616mℓ under these severe water loss conditions.

Other Russian studies[5] stated that "sailors at sea" required up to two times the volume of distilled water compared to "standard" water.

Organoleptic properties of water probably contributed to the mixed nature of the reported results : taste would probably affect the volume consumed. The preference for a water taste is learned (based on experience) and thus the human volunteers would have mixed preferences for a particular water composition.

As indicated earlier, normal day to day activities are not associated with extremes in water loss. This methodology is not appropriate for studying the effect of low TDS water on the body under normal conditions.

In further analysis of this unofficial WHO document, the following is noted :

- The animals used were anhidrotic (non sweating -dogs, rats and rabbits) and the observations were used to draw conclusions for humans which are hidrotic. Credible medical opinion has indicated that using fluid, electrolyte and acid-base data from "non-sweaters" to draw conclusion for "sweaters" is "imprudent physiologically if not scientifically erroneous"[6].
- Potential errors were never addressed.
- Mucosal damage in the G.I. tract due to consuming distilled water was reported but can not be substantiated under normal conditions. Under normal conditions, other fluids (coffee, soft drinks, etc.) are mixed wit day-to-day water consumption and, because of the internal elevation of the TDS due to secretions, the G.I. tract never experiences an consistent low TDS solution to cause mucosal cells to be damaged.
- Osmoreceptors were indicated to be in the G.I. tract. This location for osmoreceptors is unknown and no reference was given, and thus is unacceptable physiologically[6].
- The liver was implied to be a repository of salt which is also unknown and unacceptable physiologically[6].

The unofficial WHO guidelines conclusion from these studies that water containing less than 100mg/ℓ is unsuitable for drinking and causes salt leaching is not scientifically or physiologically credible.

3.3. WHO Response

WHO was contacted concerning this guidelines publication. A facsimile from WHO's Dr. H.Galal Gorchev dated January 20, 1992 refuted this conclusion, stating (in its entirety) :

"Reference is made to your fax of December addressed to Dr. Warner on the possible health effects of drinking water containing low levels of total dissolved solids. We have no information that such water would have an adverse effect on mineral balance. However, water with extremely low concentrations of TDS may be unacceptable to consumers due to its flat, insipid taste, it is often also corrosive to water supply systems."

4. Consumption of Low TDS Water : Actual Community Experience

The experience of consuming low TDS water over many years by millions of people also does not support the perception of ill health caused by this water. Several examples are discussed :

The *U.S. Navy* has used distilled water for human consumption on board ship for over 50 years. This drinking water contains generally less than 3mg/ℓ TDS. Personnel on submarines, in particular, use this water (unchlorinated for submarines) for several months at a time. Navy spokesmen have stated that they are not aware of any health problems (e.g. diarrhea) caused by this low TDS water over all the years it has been consumed[7]. The U.S. Navy formally addressed the subject of drinking distilled water in 1972. Through the Freedom of Information

Act, Captain S. W. Berg, Deputy Director for Preventative Medicine, U.S. Navy Medical Corps sent a copy of a 1972 letter addressing this subject. The letter from the Navy Surgeon General's Office indicated that consumption of distilled water is not harmful. It was also stated that, if the kidneys were impaired so that the water balance is not maintained, any water (low, medium, high TDS, polluted, etc.) can cause problems.

The *U.S. Army* uses RO units to provide drinking water for soldiers in the field. The units are designed for use on rivers, lakes, etc. where raw water has TDS levels up to 1500mg/ℓ. If the raw water TDS is low, a very low product water TDS would ensue. The only Army TDS standard is for the drinking water to be below 1000mg/ℓ. There is no minimum standard. Leaching by low TDS water was never an issue. Army studies (Lawrence Livermore Laboratories) only considered high TDS drinking water which was shown to have a "laxative" effect[8].

The *National Aeronautics and Space Administration (NASA)* has used 10 megohm water or greater(<0.05mg/ℓ TDS) on space flights. None of the health effects on humans in space identified by NASA have been attributed to this very low TDS drinking water[9].

San Ysidro. NM was the site of a test conducted for the U.S. Environmental Protection Agency(U.S. EPA) in 1987 to demonstrate the effectiveness of point-of-use RO as a means to reduce arsenic contamination in this small community of about 70 homes[10]. The TDS of the raw water was 800mg/ℓ. In addition to reducing the arsenic to levels well below the standard, the TDS was reduced to about 25mg/ℓ. After almost 10years, RO point-of-use units are still being used in this community. No ill health effects have been observed.

In communities around the world there are millions of people consuming water below 100mg/ℓ TDS. Table 2 indicates cities in the U.S. with drinking water at TDS levels below 100mg/ℓ. In addition, the TDS of Lake Tahoe drinking water is about 11mg/ℓ.

Table 2. Communities in the U.S. Reporting Low TDS Drinking Water(11)

Cities	TDS(mg/ℓ)
Baltimore, MD	89
Boston, MA	31~64
Charlotte/Mecklenburg, NC	60
Charlottesville, VA	45~61
Clackamas, OR	42~81
Denver, CO	39~216
East Bay MUD, CA	40~160
Hartford, CT	50
Manchester, NH	75~100
New York, NY	41~97
Portland, OR	22
Richmond, VA	70~153
San Francisco, CA	27~154
Seattle, WA	34~47

None of the responses indicated any related health problems over many years.

5. Conclusions

It is concluded from this study that human consumption of very low TDS water does not leach minerals from the body that cause ill health effects because;

- The human body's own control mechanism of homeostasis and internal body secretions keep tight controls on body fluid composition regardless of drinking water TDS for a normal person under normal conditions.
- The unofficial WHO document's proposed guideline of a 100mg/ℓ lower limit for drinking water due to mineral leaching and subsequent ill health was not found to be scientifically or physiologically credible. Leaching of minerals from the body is not officially recognized by WHO.
- The experience of the U.S. Navy, Army, NASA and community demonstrations do not support ill health symptoms caused by consumption of

low TDS drinking water.

- Millions of people regularly consume naturally occurring low TDS water without symptoms of ill health.

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