Chapter 7
Health Effects of De-mineralization of Drinking Water

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Abstract Desalinated water, mainly RO, but recently also produced from air humidity by condensation, is extremely low in minerals, comparable to rain water or distilled water, and even when pH-adjusted such water has low mineral content. Reduced mineral intake, due to drinking de-mineralized water, is not automatically compensated by one's diet. Especially not since there are scientific studies that show decreasing levels of a number of essential minerals in vegetables. Animal studies showed that mean haemoglobin content of red blood cells was approximately 19% lower in animals receiving non-supplemented de-mineralized water compared to animals given tap water. Higher mortality in acute myocardial infarction patients was found in regions where the drinking water was desalinated water, attributed especially by reduced magnesium intake. "Water intoxication", or delirium caused by hyponatraemia, may occur following intense physical efforts, like a marathon or working hard, and ingestion of several litres of low-mineral water. Early symptoms include tiredness, weakness, headache, brain oedema, convulsions and in severe cases coma and finally death. Electrolyte imbalance, hyponatraemia, hypokalaemia, hypocalcaemia and hypomagnesemia are the most common co-morbidities in cancer patients, which underlines the importance of minerals from drinking water. Declining dental health was reported in populations consuming desalinated water, due to low Ca and F levels in water. Drinking low-mineral water in the long run will increase the risk of acidosis, acidified tissues, as indicated by pH < 6 in urine. Thus, metabolic acidosis was reported in infants whose drinks were prepared from distilled or low-mineral bottled water. Acidosis may be a precursor to

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many diseases, e.g. cardiovascular diseases, diabetes, osteoporosis and cancer. Minerals in water are also needed to prevent corrosion and dissolution of pipe material, which makes the water unhealthy, and they are also needed for partial protection against uptake or transportation in the body of toxic elements, e.g. lead (Pb) and uranium (U).

Over 21,000 desalination plants operate in more than 150 countries in the world, including Saudi Arabia, Oman, United Arab Emirates, Spain, Cyprus, Malta, Gibraltar, Cape Verde, Portugal, Greece, Italy, India, China, Japan and Australia. Worldwide, these produce more than 13.3 billion litres of potable water each day, and provide 320 million people with drinking water. The capacity has increased exponentially over the last 30 years (Seawater Desalination 2018). Such water is extremely low in mineral element concentrations. However, water without minerals is not found in nature except for unpolluted rainwater and naturally formed ice, even if many natural waters are low in many minerals or soft (low in divalent or multivalent cat-ions), and hard waters are often artificially softened, especially in industrialized countries. Low-mineralized water, with low concentrations of Ca, Mg and HCO_3, is unstable and can be more aggressive to piping materials. Such water more readily dissolves metals, such as Cu and Pb, and some organic substances from pipes, coatings, storage tanks and containers, hose lines and fittings (Brossia 2018).

Animal studies clearly show that reduced mineral intake, due to drinking demineralized water, is not automatically corrected by one's diet. Kondratyuk (1989) reported that in a 6-month experiment on rats to evaluate the variation in the intake of microelements from drinking water there was an up to six-fold difference in their content in muscular tissue. Four groups of rats were given: (1) tap water; (2) low-mineral water; (3) low-mineral water supplemented with I, Co, Cu, Mn, Mo, Zn and F; and (4) low-mineral water supplemented with the same elements but at ten times those concentrations. The results indicated that the blood formation process was negatively influenced by non-supplemented de-mineralized water, as the mean haemoglobin content of red blood cells was approximately 19% lower in the animals that received non-supplemented de-mineralized water compared to that in animals given tap water, and the difference was even greater when compared with the animals given the mineral-supplemented waters.

The German Society for Nutrition warned the public against drinking demineralized water, and explained that water in the human body always contains electrolytes (such as K and Na) at certain concentrations controlled by the body. In addition, they stated that water resorption by the intestinal epithelium is also enabled by Na transport. Thus, if distilled water is ingested, the intestine has to take electrolytes from body reserves. Early symptoms of low electrolyte levels include tiredness, weakness and headache. More severe symptoms are muscular cramps and impaired heart rate. Thus, inadequate body water redistribution between compartments may compromise the function of vital organs (DGfE 1993). Ingestion of demineralized water leads to alterations in extracellular osmolality which can offset the osmoregulatory mechanisms: to maintain cell volume, ion transport, organic osmolyte concentration, protein structure, cell turnover, etc. (Kültz 2001).

Hyponatremic shock, “water intoxication”, or delirium, may occur following intense physical effort and ingestion of several litres of low-mineral water (Basnyat et al. 2000).

Brain oedema, convulsions and metabolic acidosis were reported in infants whose drinks had been prepared with distilled or low-mineral bottled water (CDC 1994). Osmotic changes in blood plasma due to decreasing mineral concentrations resulted in the redistribution of body water, with an increase in the total extracellular fluid volume. In response to the changed plasma volume, there was an increase in Na elimination, and enhanced diuresis (WHO 1980).

There is currently no evidence to suggest that desalinated water can cause cancer. However, acidosis may influence molecular activities at the cellular level that promote carcinogenesis or tumour progression (Forrest Robey 2012). In addition, recent epidemiological studies show that heavy consumers of de-mineralized water with very low mineral content can create osmotic imbalance by losing huge amounts of Na, K, Ca, Mg and other trace mineral elements in urine, faeces and sweat, resulting in osmotic stress. In accordance, a large number of studies have reported that electrolyte imbalance, especially hyponatraemia, hypokalaemia, hypomagnesemia and hypocalcaemia are the most common comorbidities in cancer patients (Nriagu et al. 2016).

Declining dental health has been reported from populations consuming desalinated water with very low F content, as there was a moderate to high risk of dental caries (WHO 2005).

Brown et al. (2005) studied cardiovascular response in relation to drinking distilled (hypo-osmotic) water and 0.9% saline water (isotonic) among young healthy volunteers. They found that drinking an isotonic saline solution did not change heart rate, heart rate variability, baro-reflex sensitivity or total peripheral resistance in contrast to distilled water. Drinking distilled water, on the other hand, caused a series of cardiovascular changes, including increases in total peripheral resistance, cardiac interval variability and cardiovagal baroreflex sensitivity, and a decrease in heart rate (Brown et al. 2005). Series of studies from Taiwan suggested that regular intake of low mineral and soft water increases the risk of some types of cancer (Yang et al. 1999a, b; Yang et al. 2000a, b), but possible mechanism was unknown until the study by Nriagu et al. (2016) was published. These studies should be taken more seriously, especially since this effect was confirmed by a large epidemiological study in another country, Slovakia (Rapant et al. 2015, 2017a, b). Fresh water from the Israeli National Water Carrier (NWC) is considered “hard”, with concentrations of 45–60 mg Ca/L and 20–25 mg Mg/L, while desalinated seawater contains little or no Ca or Mg. Thus, in an Israeli study higher 30-day and 1-year all-cause mortality in acute myocardial infarction patients was found in the region with desalinated seawater compared to the region supplied with hard NWC water in the years 2008–2013. In the period 2002–2006, while they were still all drinking NWC water, there was no significant difference. The researchers concluded that this may be attributed to reduced magnesium intake secondary to desalinated seawater consumption. After 1 year, 95% had survived their acute myocardial infarction in the region with hard water, while about 90% had survived in the desalinated seawater area (Schlezinger et al. 2016).

In a Jordanian study, Ca intake from water was compared with total Ca intake. Sixty-three percent of the Jordanian people who live in Amman, 43% living in Irbid and 30% living in Zarqa depend on reverse osmosis (RO) water for drinking and cooking due to high salinity in tap water. The water contains no more than 6 mg/L Ca. Calculations showed that Ca intake where RO water was mostly used was less than the recommended amount. The authors concluded that if the reduction in Ca intake is not balanced in the diet, serious health problems such as osteoporosis may be the result especially in elderly people and women (Mousa et al. 2010). Between 2003 and 2010, the use of thyroid disease medication among Israeli adults increased from 2.9% to 4.7%, and during this time a large number of seawater reverse osmosis desalination plants were built along Israel's coast, eliminating almost 100% of iodine from drinking water. The Ashkelon desalination plant is the major source of drinking water in the Ashkelon District. Researchers obtained data on iodine status in adults in the Ashkelon district without reported or known thyroid disease. Results showed possible iodine deficiency (Tg $\geq$ 10 μIU/mL) among 76% of the participants, which was higher than that reported a decade ago (Ovadia et al. 2013).

In addition to Ca and Mg, tap water and bottled waters may contain various concentrations of HCO_3, influencing the mineral homeostasis. HCO_3 is the main pH regulator in drinking water. Its importance is most probably underestimated, and can explain a big part of the pathologies resulting from drinking low mineral water. Thus, besides achieving the recommended amount of Ca and Mg in drinking water, a recommended level of 250 mg/L for HCO_3 has been suggested. As mentioned in Chap. 1, the net endogenous acid production is in close relation to excretion of both Mg and Ca (Rylander 2008).

In drinking water, pH alone is not the primary determinant of adverse effects on human health, since acids and alkalis are normally extremely dilute. Thus, although pH has no direct impact on the human body, it is one of the most important operational water quality parameters. The optimum pH will vary in different supplies according to water composition and to the nature of the piping materials used in the distribution system. However, Rosborg et al. (2002) stated that the mineral content was highest in the pH range 7–8, as minerals have been washed out from soils at low pH levels, and especially Ca salts tend to precipitate at pH exceeding 8. Because pH can affect the degree of metal corrosion, as well as disinfection efficiency, the authors (WHO 2005) declare that any effects on health is likely to be indirect and due to increased ingestion of metals from plumbing materials and pipes or due to inadequate disinfection, as well as due to low HCO_3 content resulting in higher Mg and Ca urinary losses, as mentioned above.

As discussed in connection with hard versus soft drinking water, the intake of soft water may increase the risk of cerebrovascular diseases (Yang 1998), fractures in children (Verd et al. 1992), certain neurodegenerative diseases (Jacqmin et al. 1994), pre-term birth and low weight birth (Yang et al. 2002), some types of cancers (Yang et al. 1999a, b, 2000a, b), death from cardiovascular diseases (Catling et al. 2008), increased risk of premature sudden death (Eisenberg 1992; Bernardi et al. 1995; Garzon and Eisenberg 1998), increased risk of motor neuronal diseases (Iwami et al. 1994; Melles and Kiss 1992), and pregnancy disorders (preeclampsia) (Melles and Kiss 1992).

Ca and, to a lesser extent, Mg in water and food are known to have antitoxic properties. They can help prevent the absorption of some toxic elements, such as, Pb, U and Cd from the intestine into the blood, either via direct reaction leading to the formation of an unabsorbable compound or via competition for binding sites (Levander 1977; Nadeenko et al. 1987; Kozisek and Rosborg 2008). Kozisek (2005) also states that populations supplied with low-mineral water may be at a higher risk in terms of adverse effects from exposure to toxic substances, such as Cu or Pb, compared to populations supplied with water of average mineralization and hardness, due to corrosion of pipe material. Although this protective effect is limited, it should not be dismissed.

The use of de-mineralized water also has effects on minerals from food. Losses of up to 60% of Ca and Mg have been reported when vegetables were boiled in de-mineralised water, and even more for some microelements; Cu: 66%, Mn: 70% and Co: 86% (Kozisek 2005). See the second box below for more information on this effect. In times when even former fertile areas are depleted of essential micro minerals like Se, Mo, Cr, Mn, etc. due to fertilization with only NPK (nitrate, phosphate and potassium), elements in vegetables and other plants also decrease, making drinking water minerals nowadays even more important than in the past. Since the 1850s, wheat has declined in Mg concentration by 7–29% in the USA and Mg in vegetables declined by 15–23% from the 1930s to 1980s (Rosanoff 2013).

The Armed Forces Medical Services (AFMS) of India declared: "As medical authorities we should advise and persuade administrative authorities to discourage tendencies of installing desalination/RO plants in the name of welfare or on demand of ill-informed clientele on the sake of "water fad" (without having scientific basis) to protect people from chronic diseases. The requirement of these should be assessed taking into consideration of geological parameters and chemical report of available water source in the area and be installed through authorized agencies with inbuilt mechanism for control, monitoring and evaluation of quality of processed water to safe guard health of the personnel in longer run". (Verma and Kushwaha 2014).

Many schools in China introduced as preventive measure (to improve water quality) so-called direct drinking water systems that utilize reverse-osmosis (RO) – thousands of children are drinking, not as their choice, very low mineral drinking water. A recent Chinese study addressed the influence of regular drinking of such water on children's health, especially on their development. Within an eco-epidemiological study, the authors collected developmental parameters of 13,723 girls and 16,161 boys before and after the introduction of RO drinking water systems in 25 schools and measured the mineral levels in water in each school. Water in 22 schools had lower than recommended levels of magnesium and calcium (Mg 10 mg/L and Ca 20 mg/L). The study found that children exposed to low-mineral water exhibited reduced height and diminished height increases as well as higher prevalences and incidences of hypoevolutism and dental caries with statistical significance. The results suggest that low-mineral water may retard height growth and promote the incidence of dental caries in schoolchildren and that the schools should choose another treatment system that retains the minerals in water (Huang et al. 2018). The follow-up case-control study involving 660 children confirmed that consumption of very low mineral water may be associated with osteoblast inhibition, bone resorption activation, bone mineral reduction, and height development retardation (Huang et al. 2019).

According to the study done in Qatar, pH-adjusted desalinated bottled water may cause deficiencies in nutrient mineral elements as it only accounted for 3% of the Institute of Medicine (IOM) Adequate Intake (AI) for Ca, 5–6% of the Recommended Daily Allowance (RDA) for Mg and 4% of the AI for F among adults. For children, desalinated water contributed 2–3% of the IOM AI for Ca, 3–10% of the RDA for Mg and 3–9% of the AI of F. On the other hand, Qatar's population is not at elevated risk of dietary exposure to As, Ba, Be, Cd, Cr, Pb, Sb and U from consumption of both desalinated and non-desalinated bottled water types available in the country (Rowell et al. 2015).

Case Studies of People with Health Problems After Drinking Osmotic Water: Experience from the Czech Republic

Information on single cases collected in a casual or informal manner and relying mostly on personal testimony, also called anecdotal evidence, have been considered for a long time as secondary information of limited value, not fitting in serious research. However, the times and our knowledge are changing and also use of anecdotal evidence gained its recognition and place in science. It was found, that some important information, e.g. about adverse effects of drugs and food products, is possible to get relatively quickly and effectively only in voluntary cooperation of consumers. That is why the specials reporting systems of adverse events have been developed and operated, e.g. FDA's Adverse Event Reporting System (FAERS) in the USA for drugs or Nutrivigilance in several EU member states for food products and dietary supplements.

We find similar situations in drinking water where quality was unusually changed (all total dissolved solids were removed), but not on the level of population supplied by municipal water supply, but on the level of single households. It would be very difficult to make any controlled epidemiological study – at least because it would be very difficult to get ethical approval if we know that a certain type of water treatment represents risk for health. That is why information on adverse health effects from people who bought and installed home water treatment device based on reverse osmosis or distillation in good will is very valuable to our knowledge on effects of low-mineral water on human health. Especially if more detailed information is collected from the consumers.

Awareness about health significance of nutrients in drinking water is quite common among professionals in public water and health in the Czech Republic (CR) since the 1960s, when the first studies on water hardness and

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health were published. This was reflected in recommended optimum values for hardness in the national standard for drinking water quality. Home water treatment units have been marketed and sold since 1990 in the CR, based solely on GAC, mechanical filters, or ion exchange (mostly for nitrate removal) until about 2000. Reverse osmosis (RO) units were used only for laboratory or various industrial purposes at that time.

Then in year 2000, several companies started to sell RO units also for home drinking water treatment. However, after only a few years proper regulatory framework was accepted and limited the use of RO units in a safe manner for consumers (see below). At this time dozens of people turned either spontaneously or on recommendation of the Regional Public Health Authorities to the National Institute of Public Health (NIPH) in Prague to share quite consistently their negative experiences after drinking water treated by RO. The NIPH was addressed in this issue by more than 50 people from the CR and some from Slovakia. The NIPH had the opportunity to study parts of these cases (24 people of 16 households) in more detail through directed interview or written questionnaire, water sampling, or results of laboratory analyses and several medical reports.

All these people were supplied with safe drinking water from public supplies. They bought the RO units because of unfair arguments of dealers that tap water is unsafe and not sufficiently monitored. All treatment units consisted 4 treatment steps: mechanical filter, GAU filter, RO membrane, and re-mineralization cartridge.

While drinking water supplied contained total dissolved solids (TDS) in the range 160–450 mg/L, Ca 25–103 mg/L and Mg 2–16 mg/L, water treated by RO units (even after "re-mineralization") had consistently negligible content of essential minerals: TDS 14–55 mg/L, Ca 0–7.2 mg/L (mostly less than 3 mg/L) and Mg 0–8.8 mg/L (mostly less than 1 mg/L).

All interviewed consumers, mostly middle age families with children with healthy lifestyle, started to drink water treated with RO with expectations to better protect their health, but sooner or later they started to have various health problems, although they were in most cases without any health problems before. The age range of cases that reported health problems was between 2 months and 66 years and the first signs of health problems appeared usually within several months after consumption of RO-treated water (on average 4 months, with a broad range; 2 days – 10 months). The reported health problems were extreme fatigue, malaise, nausea, headache, brittleness of nails and hairs, leg and abdominal cramps, pre-eclampsia and twitch, and in several cases also metabolic acidosis, cardiovascular disorders (arrhythmia, stroke, aneurysm), higher diuresis, leg oedema, giddiness and diarrhoea.

Some people complained about the taste of the treated water (no taste, unpleasant or strange taste, like chewing paper, not quenching thirst). When

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people realized that there was a relationship between their health problems and water quality, they stopped to drink the osmotic water and started to drink untreated tap or bottled water again, and in most cases health problems disappeared, but it took several weeks or months. Only some people needed medical treatment. NIPH also were informed about several deaths of people drinking osmotic water, but had no possibility to search for more details and causality.

In reaction to this situation, the public health authorities amended the regulation on products in contact with drinking water, which also covers home water treatment units. Current Czech regulation (Decree of the Ministry of Health No. 409/2005 Coll. on the hygiene requirements for products coming into direct contact with water and for water treatment) requires that these units should not decrease the hardness to more than 10%, or – if it is specifically designed to soften or partially de-mineralize water – it should keep minimum mineral levels in treated water as follows: TDS > 150 mg/L, Ca > 30 mg/L and Mg > 10 mg/L. Units not complying with this regulation should not be marketed. In practice this means that RO units without by-pass cannot be marketed as suitable for drinking water treatment as only re-mineralization cartridge cannot provide the required minimum. According to the NIPH experiences, based on analyses of water treated by dozens of RO units equipped with re-mineralization cartridge, the level of re-mineralization is absolutely insufficient from a health point of view as it can usually only provide less than 5 mg/L (Ca) or 2 mg/L (Mg).

The only possible use of RO units for home water treatment is in the situation that water (usually in private well) has high TDS and the by-pass in the RO unit is adjusted in the way that the treated water meets minimum Mg, Ca and TDS requirements. If water before treatment has already lower than minimum levels of Ca and Mg, it cannot be treated by RO. Since this regulation came into force, marketing of RO units for home water treatment without by-pass practically stopped and the number of people reporting health problems decreased substantially (Kozisek 2010, unpublished so far).

Some case studies of people with health problems after drinking osmotic water are included in the box.

In studies from Slovakia by Rapant et al. (2017b), the scientists suggested that the recommended levels of Ca and Mg in Slovakia should be increased from current Ca more than 30 mg/L and Mg 10–30 mg/L to Ca more than 89 mg/L and Mg 24–96 mg/L. The presented optimum range for Mg was 42–78 mg/L. Their study was based on ReI (relative mortality for cardiovascular diseases) data in relation to chemical composition of ground water in the Slovak Republic. The authors conclude: "Based on the achieved results, we recommend that the World Health Organization consider revising their definition of drinking water quality standards for Ca and Mg contents and water hardness."

In the late 1970s, WHO commissioned a study to provide background information for issuing guidelines for desalinated water. The final report concluded; "not only does completely de-mineralized water (distillate) have unsatisfactory organoleptic properties, but it also has a definite adverse influence on the animal and human organism" (WHO 1980). In spite of the fact that this knowledge has been confirmed by a number of studies and any one did not impeach it, the approach of the WHO to the regulation of this area is very flabby, although the use of desalination increases continuously. Kozisek (2005) states that the four countries, Czech Republic, Hungary, Slovakia and Poland, that became part of the EU in 2004 included requirements of a minimum accepted hardness or levels of Ca and Mg in their respective regulations of drinking water. The awareness of the importance of minerals from drinking water is higher in these countries than in the Western parts of the EU, for historical reasons.

Some examples of boiling food in waters with different mineral contents are presented in the box.

Changes in the Mineral Content of Foods When Boiled in Waters of Different Hardness

Once an inverse relationship between water hardness and cardiovascular mortality was found and confirmed by a number of epidemiological studies in the 1960s and 1970s, some scientists began to suggest possible explanations or mechanisms of unexpectedly high magnitude of health effects in comparison with minor contribution of water to total daily intake of essential elements like calcium (Ca) and magnesium (Mg). For example, a systematic review of analytical studies investigating the association between cardiovascular disease and drinking water hardness (Catling et al. 2008) proved that 25% difference in mortality was caused by water Mg difference of only 10 mg/L (ca 5 vs. 15 mg/L). Considering daily water consumption of 2 L, it means the difference in Mg consumption is 20 mg/day, which represents only less than 10% of the recommended daily intake (280–350 mg for different populations).

One explanation is influence of water hardness on mineral content in food cooked in such water (potatoes, pasta, rice, some vegetables). If we cook these food items in soft water, there are higher losses of some essential elements into water, which is finally poured out. Consumers have in such situation not only lowered intake of nutrients (Ca, Mg) from soft water, but also from food. Unfortunately there have not been many studies looking into details and quantifying this effect.

The first benchmark experiments were done already in the early 1960s in the UK, where hard London water and very soft Glasgow water were used for cooking several sorts of vegetable and analysing cooking liquors for Ca (DSIR 1964). All the vegetables lost Ca to soft water and gained some Ca from hard

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water. However, the first regular experiment and its result were published by Dutch authors in 1981 (Haring and van Delft 1981). They cooked 4 food items (potato, cauliflower, carrot, and endive) in 6 different municipal tap waters of different hardness ranging from 0.6 mmol/L (Ca 17 mg/L; Mg 3.6 mg/L; conductivity 17 mS/m) to 3.6 mmol/L (Ca 114 mg/L; Mg 19 mg/L; conductivity 60 mS/m) and analysed mineral composition of the foodstuff. The most significant differences were found for Ca: the concentration of this element in potatoes and vegetables usually increased when cooking with hard-water types and decreased when soft water was used for cooking. Content of Mg in food decreased after cooking in any type of water, but losses were a little lower after cooking in hard water.

Similar types of experiments were conducted 25 years later at the National Institute of Public Health in Prague (unpublished results), using different foods (potatoes, pasta, beans, cabbage) and three municipal tap waters of various hardness: A) hardness 3.6 mmol/L (Ca 106 mg/L; Mg 13.5 mg/L; conductivity 42 mS/m), B) hardness 1.1 mmol/L (Ca 27 mg/L; Mg 3.5 mg/L; conductivity 15 mS/m), C) hardness 0.6 mmol/L (Ca 9 mg/L; Mg 3.7 mg/L; conductivity 13 mS/m). The results confirmed important impact of cooking on mineral composition of food and different behaviours of Ca and Mg. While losses were found in Mg (with the exception of pasta with 13% increase when cooked in hard water, and 7–8% decrease when cooked in soft waters), ranging from 25 to 50% with slight protective effect of hard water in the case of potatoes, more pronounced differences were found in the case of Ca. Its content in pasta and beans increased after cooking in all three waters, but six times higher in pasta in hard water than in soft water, and 2–3 times higher in beans in hard water. Ca content in potatoes increased after cooking in hard water by 83% (in comparison with raw potatoes), but after cooking in soft waters both slight increase (by 18%) and decrease (by 10%) was found. Ca content in cabbage did not change significantly after cooking, it differed by minus 7% to plus 3% (hard water) in comparison with raw cabbage (Kozisek, personal communication).

Thus the results show the real impact of water hardness on mineral composition of vegetable and other foodstuff cooked in the water.

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