Age-Related Changes in Hydration

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Introduction

Normal aging is often described as a continuous process characterized by a decrease in lean body mass, an increase in fat, and a decrease in total body water. However, it has been pointed out that many older people, especially those aged 75 years and over, may feel healthy in spite of a chronic illness [1]. Thus, both nutrition and hydration may be altered by chronic diseases, infection, as well as by changes in functional status, mobility disorders, confusion, impaired sensory perception, medication effects and difficulties in drinking, swallowing and eating because of the absence of teeth or ill-fitting dentures. For water balance, two factors place the elderly at risk for dehydration: a decreased fluid intake and an increased fluid loss. In the human, the normal pattern of drinking is intermittent while water is continuously lost by various routes so that dehydration occurs. Dehydration is the most common cause of fluid and electrolyte imbalance and is frequently reported in residents, hospitalized and community-dwelling elderly people. It has been stated that one of the greatest threats to the survival of any terrestrial animal, including man, is that of dehydration [2]. In this chapter we review the factors which may disturb fluid balance and predispose elderly to dehydration, the mechanisms involved and the changes in body water compartments. The possible health consequences of dehydration and the new recommendations of fluid intake in elderly populations are also discussed.
Table 1. Water needs throughout human life [9]

<table>
<thead>
<tr>
<th>Age</th>
<th>Volume ml/kg/24 h</th>
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<tr>
<td>1 day</td>
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<td>2 days</td>
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<tr>
<td>50 years</td>
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<td>&gt;65 years</td>
<td>30</td>
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**Fluid Balance**

*Fluid Consumption*

Large cultural variations in the type of beverages consumed have been shown, and in 1991 an increasing tendency to drink beverages rather than plain water was observed. In Germany, a survey on beverage preferences showed that a majority of respondents had a negative attitude towards drinking tap water whereas mineral water was regarded very positively [3]. Water and beverage consumption has been evaluated in the SENECA study including 629 men and 696 women born between 1913 and 1918 and living in small traditional European cities. The results showed that daily water intake in women was less than 1.7 liters and that their risk of dehydration was higher when compared to men because of their lower water intake. In almost all towns, the consumption of mineral and drinking water, tea, coffee, cocoa drink and carbonated or non-carbonated drinks contributed mostly to the daily fluid intake [4]. In France, a nutritional survey in 45 men and 55 women aged 65 years old has shown that 33% of the subjects drink mineral waters and that the total daily water intake reaches 952 ml [5]. Recently, a review of the literature on the quantity of fluid consumed by healthy elderly concluded that the approximated intake of 2.1 liters was not less than the average fluid intake of young adults. The authors attributed the general opinion of a significantly lower water intake in the elderly to the tendency to underestimate the real intakes in this population [6]. Three standards of fluid intake have been established and applied for the elderly. One corresponding to a fluid intake of 30 ml/kg body weight (Table 1), the second corresponding to 1 ml/kcal energy consumed and the third corresponding to 100 ml/kg for the first 10 kg, 50 ml for the next 10 kg and 15 ml for the remaining kilograms. These standards were compared in 40 institutionalized
elderly residents included in 2 age groups: 65–85, and 86–100 years. The results showed that this population received adequate fluid intake according to the 30-ml/kg body weight standard. However, in that case unrealistically low fluid recommendations were proposed in underweight residents. On the contrary, more than adequate fluid intake was observed when 1 ml/kcal energy consumed was applied and inadequate fluid intake was found with the third standard. However, this standard appears to be more reasonable for patients whether they were of normal weight, underweight or overweight and supported other recommendations of 1.5–2 liters of daily fluid intakes [7]. Finally, a 7-day estimated dietary record was validated in 31 geriatric patients aged 86 years and located in five nursing home wards in Sweden. A mean daily water intake of 1.787 liters was found and a mean daily water loss of 1.774 liters as assessed by $^2$H dilution from the administration of doubly labeled water ($^2$H$_2^{18}$O) was seen. The 7-day dietary record seemed adequate for geriatric patients as the estimated water intake from food and beverages was not different by more than 1% compared to the labeled water method [8].

Control of Fluid Intake
Taste and Odor

Poor oral health is widespread among elderly. Both odor perception and dental health are linked with oral cavities which may affect both food and fluid consumption. A study performed on 200 independently living elderly aged 60–90 years has established the relationship between age and odor perception for nutrient and fluid intake. The results showed that odor perception declined with age. No significant correlation was observed between nutrient intake and odor perception except for water and energy, showing that poor odor perception is associated with diminished intake. A significant separate relation (multivariate statistical testing with path analysis), controlling for age, was shown between odor perception and water intake, indicating that good odor perception is associated with higher water intake. People with high water intake tend to consume more drinks from habitual fluid intake as well as more nutrients containing savory foods such as soups and sauces [10]. Saliva plays a prominent role in taste function and older adults with dry mouth can experience changes in taste perception. However, recent studies have revealed that in healthy older adults, there is no general diminution of saliva produced and no significant alterations in the composition of saliva. In spite of these observations, many older adults complain of a dry mouth and have decreased salivary output. These problems are most likely caused by drug treatments rather than by aging [11] as well as dehydration. Taste and odor perceptions are modified by dehydration. The term ‘alliesthesia’ was used to describe this phenomenon whereby the stimulus could be perceived as pleasant or unpleasant depending upon the internal status of the subject. If taste perception is decreased by dehydration the fluid intake will be reduced.
Thirst

The ingestion of a sufficient volume of fluid to maintain body water balance requires that thirst perception be present. In 1958, it was suggested for the first time that thirst perception may be altered in the elderly [12]. In 1978, a clinical study performed on young (n = 25, mean age 30 years) and old (n = 25, mean age 75 years) hospitalized patients showed a reduced water intake of 549 and 1,440 ml, respectively. When infused with 5% NaCl, thirst perception was noticed after 7.5 and 18.5 min for the young and old patients, respectively. The increase in osmolality was 9 and 27.1 mosm/l and total water intake for the 90 min following thirst perception was 1.055 and 0.234 liters, respectively [13]. In 1984, using a water deprivation protocol in healthy young and 65-year-old men, it was confirmed that despite their obvious physiologic needs the elderly subjects were not markedly thirsty and their water intake was reduced [14]. It has been shown in the elderly that there was no alteration in thirst ratings despite increasing plasma sodium levels and osmolality, these changes indicated that an osmotic thirst stimulus had occurred. Thirst is also reduced in the elderly in response to heat stress and thermal dehydration [15]. Age-associated reduced thirst perception may predispose these individuals to disturbances of fluid balance and to dehydration because a deficit in body water content can only be eliminated by fluid intake. The underlying mechanisms for these impairments in the elderly have not been fully elucidated. However, a number of studies have examined the role of osmoreceptors and volume receptors. In all mammals, raised plasma osmolality is more important than reduced volume in the stimulation of drinking. There are indications that aged humans may have a diminished volume receptor sensitivity but normal osmoreceptor sensitivity [16]. It is frequently suggested that a decrease in blood volume by 5% through dehydration is necessary to induce thirst stimulation in elderly people. In spite of normal osmoreceptor sensitivity, thirst becomes evident in healthy young individuals when plasma osmolality rises to values of >292 mosm/l while healthy persons 67–75 years old showed a diminished subjective awareness of thirst for plasma osmolality of >296 mosm/l [17].

The characteristics of the osmoreceptors governing thirst and vasopressin release are similar but may be anatomically and functionally separate in humans. Baroreceptor sensitivity declines with age and this change affects the release of vasopressin, although it is not clear whether hypovolemic stimuli evoke normal thirst in the elderly. There are some preliminary results suggesting that hypodipsia of the elderly may be due to alterations in the endogenous opioid system [15].

Changes in various neurotransmitters may influence thirst in the elderly. A reduction in central dopamine may be responsible for reduced thirst in the elderly patient. The normal aging process affects other hormonal systems involved in thirst such as atrial natriuretic peptide secretion and decreased angiotensin II which may be partially responsible for a reduction in
thirst sensation in aged people [18]. There are other signals issued from the oropharynx that trigger thirst.

The most important limitations of water intakes are the impairment in the mechanisms regulating thirst, and for water losses it is the decrease in the urine-concentrating ability of the kidney.

**Control of Fluid Loss: Kidney Function**

Kidneys play a major role in the control of water and electrolyte homeostasis. The main changes in renal function with age are the decline in the glomerular filtration rate due to sclerosis, the reduced urinary-concentrating ability, the less efficient sodium-preserving capacity and the reduced ability to excrete a water load. Kidney mass progressively declines from a normal weight of 250–340 g in young adults to 180–200 g in the elderly aged 80–90 years. This decline is primarily due to atrophy of the renal cortex and represents approximately 40% loss of renal volume [19].

The anatomical changes in the aging kidney are paralleled by alterations in renal functions. Glomerular filtration rate remains stable until 40 and then declines with considerable individual variability at an annual rate of 1 ml/min. Renal blood flow declines during normal aging by 10% per decade so that, by the age of 90 years, the renal plasma flow is 300 ml/min, a 50% reduction in the value found at 30 years of age. The changes in the diluting capacity of the aging kidney were evaluated by determining the minimum urine osmolality and maximum free water clearance after water loading. For urine osmolality, the value increased from 52 mosm/l in young men (31 years) to 74 mosm/l in middle-aged men (60 years) and 92 mosm/l in older men (84 years). Free water clearance calculated from water load administration reached 8.4 ml/min in healthy young subjects (22 years) and was reduced to 5.7 ml/min in the older group (72 years). In this study, these indices were not significant when adjustments were made for changes in creatinine clearance while other investigations reported a significantly lower free water clearance:creatinine ratio in elderly people. All these changes in the kidney and a narrowing of other homeostatic mechanisms that occur with aging can increase the risk of developing water intoxication and in other situations either sodium retention or excess sodium excretion [17]. It is essential for clinicians to be aware of the pathophysiology of hypo- and hypernatremia in the elderly patient. A detailed review article on the current knowledge of the histological and physiological processes of aging in the kidney has recently been published [20]. These age-related changes as well as chronic diseases and a decrease in total body water make elderly persons markedly susceptible to stresses on water balance and postural hypotension. In addition, incontinence is often reported with aging and as a consequence water intake is reduced to prevent frequent urination, possibly leading to chronic dehydration.
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**Mechanisms of Water Balance**

There are many other parameters which have been reported to change with aging such as hormonal responses and neurotransmitters release. The central control of water balance through ‘hypothalamo-neurohypophysis’ was first shown in 1950 in animal experiments [21].

The extracellular osmotic pressure is precisely controlled by receptors located at the bottom of the brain *organum vasculosum* of the *lamina terminalis* of the third brain ventricle. The impulses are transmitted to neurons of the supraoptical and paraventricular nucleus of hypothalamus. These neurons synthesize arginine vasopressin (AVP) or antidiuretic hormone which inhibit water elimination from the kidney. Although there are discrepancies between results on plasma AVP concentrations, its release does not seem to be impaired with aging. However, AVP levels are increased for any given plasma osmolality level, indicating a failure of the normal responsiveness of the kidney to AVP and a decreased sensitivity of the receptors of the tubular cells. In addition to the age-related changes in the vasopressin system, atrial natriuretic hormone and the renin-angiotensin-aldosterone system, there are many other endocrine systems which are associated with aging [22].

**Body Water Compartments: Extra- and Intracellular**

Body water plays several roles such as the regulation of cell volume, the transport of nutrients, the elimination of metabolic products and the regulation of body temperature. Water is the most abundant human body constituent ranging in adults from 50 to 65% body weight, depending upon age, gender, muscle mass, and the level of physical activity. Total body water manifests a linear decrease with aging, until it constitutes less than 50% of body weight in very old individuals. There is thus a mean decrease of 0.3 liter in total body water during the period of life from adulthood to old age. This loss seems then to increase even later after 70 years. In women, body water loss is limited and in adults it is shown to increase after 60 years, while in men there is a more constant change. These differences are linked to the decrease in fat-free mass which contains more water (73%) and therefore it is the loss of water from the intracellular compartment which explains the total body water loss in the elderly (Fig. 1) [23].

Recent studies were performed to compare hydration in young and elderly people, particularly the age-related changes in the proportion of intracellular or extracellular water to total body water. The first study of this multicentric trial (the Source Study) in 68 healthy elderly (66.1±0.6 years) and 35 young adults (38.1±4.3 years) measured total body water using the $H_2^{18}O$ dilution technique and extracellular water using the bromide technique. As shown in Figure 2, the proportion of intracellular or extracellular water was similar
so that hydration of fat-free mass and cellular hydration are not affected in healthy aging [24]. An additional group of 85 aged diseased patients (80.5±1.0 years) in the Source Study demonstrates that extracellular water was higher in aged patients than in healthy elderly subjects. The proportion of extracellular and intracellular water to total body water was the same in adults and in healthy elderly subjects (Fig. 2). Total body water and intracellular water were higher in adults than in the 2 groups of elderly people. These values
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![Graph showing the relationship between extra- and intracellular water compartments with total body water in healthy elderly and aged patients. Adjusted mean extracellular water compartments were higher, and intracellular water compartments were lower in aged patients than in healthy elderly persons [25].](image)

were also higher in the healthy elderly than in aged patients [25]. Bioelectrical impedance analysis (BIA) was finally applied to 169 geriatric patients with varying degrees of hydration and compared with the results of total body water and extracellular water obtained with H$_2$O$_{18}$O and bromide dilution technique. The results obtained in the 3 groups of dehydrated ($n = 44$), euhydrated ($n = 67$) and hyperhydrated ($n = 58$) show that significant differences in total body water were measured with BIA and $^{18}$O dilution, and that these differences were not affected by the hydration status. A new equation was
proposed to accurately estimate body water spaces with BIA in geriatric patients [26].

**Dehydration and Hyperhydration**

In 1991, the Medicare program, which included more than 10 million people in the USA, stated that dehydration represented one of the five major diagnoses in the elderly: 6.7% i.e. 731,695 hospitalized patients. About 50% of the hospitalized elderly with dehydration passed away in less than 1 year after their admission and 18% in less than 30 days. About 1.1% of the hospitalized patients older than 60 years suffered from hypernatremia [27]. A review published on all studies performed between 1976 and 1995 showed the importance of dehydration in the elderly and the difficulties in preventing dehydration [28]. Increasing age is a major risk factor for dehydration and persons older than 85 years were shown to be six times as likely to develop dehydration.

Dehydration has multiple origins including disturbances of physiological functions, mobility disorders, associated illness such as infection, the use of diuretics or laxatives, poor dietary and oral fluid intake and the absence of air conditioning during periods of hot weather as well as the limited access to regular medical care. Several forms of dehydration have been described taking into account water and sodium imbalance. Isotonic dehydration results from a balanced loss of water and sodium from diarrhea or vomiting. Hypertonic dehydration occurs when water losses are higher than sodium losses and is characterized by hypernatremia, sometimes with hyperkalemia and with osmolality higher than 300 mosm/l and plasma sodium concentrations of more than 145 mmol/l. Fever is the most common cause of hypernatremic dehydration. Then, hypotonic dehydration occurs when sodium loss exceeds water loss. Plasma sodium concentrations are lower than 135 mmol/l and osmolality less than 280 mosm/l.

Dehydration is often mentioned as a major risk factor in the increased morbidity and mortality of elderly people. It is noticed that the diagnosis of hydro-electrolyte imbalance from a medical examination leads to frequent errors. It is thus essential to detect and prevent dehydration and finally to evaluate its occurrence and its consequence with sensitive and accurate tools.

Biological parameters (hematocrits, blood protein, blood urea and blood creatinine) have been used to show dehydration. In elderly humans, significant increases in plasma sodium and osmolality have been reported following a 24-hour period of fluid deprivation [15]. However, analytical results are often difficult to interpret because dehydration can occur with normal or lower sodium blood concentrations, which does not demonstrate an imbalance of water homeostasis. Large variations in osmolality are reported in the elderly and it has been suggested that higher values are correlated with an increased
mortality. In adults the range of osmolality values is 278–305 mosm/l while in the elderly this range is extended to 164–317 mosm/l, and is thus difficult to use as a diagnosis. Clinical studies have shown that 11% of the hospitalized aged patients exhibit sodium and osmolality abnormalities. The occurrence was even higher, and reached 22 and 35% [29] in patients coming from residences for elderly people.

In addition to plasma osmolality, sodium or urea concentrations, most clinicians use physical signs to determine dehydration: tongue dryness, longitudinal tongue furrows, sunken eyes, dry mucous membranes, nausea, constipation, upper body muscle weakness, confusion, speaking difficulty, decreased urination, hypotension and chronic infection. But these clinical criteria used by most physicians to establish a diagnosis of dehydration in a population of elderly subjects are not reliable [29]. However, it has been recognized that the tools necessary for rapid and accurate evaluation and without disturbance to the patient are not yet available so that the consequences of marginal and chronic dehydration are unknown. Body weight control is the most sensitive measurement of acute dehydration, and new studies and developments in BIA described previously may be an efficient method for the diagnosis of acute or chronic body water imbalance.

Among the pathologies which increase the risk of dehydration are infectious diseases, pneumonia and flu leading to fever, bronchorespiratory diseases, gastroenteritis. A more specific disease such as Alzheimer’s, which is shown to induce an increased plasma osmolality in the morning after nocturnal dehydration, may aggravate body hydration and homeostasis. Deterioration in cognitive functions, skills or abilities increases the risk of dehydration as well as drug treatments, such as diuretics and laxatives. There is an age-dependent change in drug metabolism and elimination, and attention must be paid to maintaining adequate fluid intakes to prevent iatrogenic toxicity in the elderly. Several studies have shown a beneficial effect on hydration of drug treatments when medications are taken with water [7].

In addition to these physiological and pathological modifications, behavioral constraints are related to the limitation of movements. It was shown that physically activity was a key factor predicting non-disability in men and women aged 65 years and older before death [30]. Limited physical activity is also responsible for muscle mass loss called sarcopenia which leads to the observed decrease in total body water content in the elderly. Walking and other exercise programs are generally acknowledged to offer benefits to many older persons and to have no detrimental effect on hydration. On hot days, however, any benefits of exercise to the over 50-year-old persons may parallel an increased risk of dehydration and hyperthermia [31].

In 1995, the American Medical Association mentioned that there was no absolute definition of dehydration. One definition is the rapid weight loss of over 3% of body weight while mild dehydration is often defined as a 1–2% loss of body weight caused by fluid loss. As a consequence, dietary guidelines
of daily water intake differ between countries and the real incidence of dehydration may be underestimated in older persons but overdiagnosis may also occur [28]. Recent evaluation of fluid intake in healthy elderly persons shows that they drink approximately 2.1 liters of fluid/day, an intake similar to healthy young adults [6]. Another study confirmed these results but showed that a high percentage of elderly people has a water intake below the cutoff value of 1.7 liter established by the Dutch Nutrition Board [4]. Finally, a mean daily water intake of 1.7 liters was confirmed [8] so that a minimum recommendation of 1.5 liters [32] or a range between 1.5 and 2 liters was proposed [7]. In 1999, a proposal was made to modify the food guide pyramid for people over 70 years of age [33]. At the bottom of the pyramid was an added water intake equal to or greater than 8 glasses, i.e. 2 liters/day to prevent dehydration. This recommendation is questioned because it is well documented that elderly persons are less able to excrete a water load and are more prone to develop water intoxication with excessive water intake. The evaluation of this risk has been performed in a population with a mean age of 74.1 years where fluid intake and natremia were recorded. The self-reported fluid intake for 796 participants in the New Mexico Elderly Health Survey showed that most of them (71%) had a fluid intake equal or exceeding 6 glasses/day. Evidence of hypernatremia was observed in 227 individuals with a lower water intake. In contrast, hyponatremia was rare in this population including frail elderly, homebound and those in nursing homes. This study was not able to show the potential beneficial versus adverse associations of the 8-glasses/day recommendation [34]. Afterwards it was proposed to limit these recommendations to 6 and not 8 glasses of water daily to healthy elderly people and to increase water intake by 2 glasses under stressful conditions [35]. It would be even more appropriate to express water intake in liters (8 oz (2.36 dl) or 12 oz (3.54 dl)) instead of servings or glasses as gerontological nurses in their everyday practice found the use of 4-ounce glasses rather than 8- or 12-ounce glasses more acceptable [36] for meeting the individual needs of their heterogeneous population of elderly patients.

References


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Discussion

Dr. Taylor: Some years ago, there was a proposal by Harding [1] from Oxford that dehydration very early in life was associated with cataract. Have you found any information on that?

Dr. Arnaud: We are not aware of any data on cataract and dehydration. There are data on kidney stones and dehydration. It is known that kidney stone formation occurs during the night, between 11 p.m. and 6 a.m., and it is also linked to climate. The possibility that nocturnal dehydration might be a factor in cataract is interesting and would be worth examining.

Dr. Endres: Can you tell us something about the differences between tap water and mineral water. There are many people who do not buy mineral water and prefer tap water.

Dr. Arnaud: Drinking natural mineral water is originally a European commodity and habit. The European legislation about bottled mineral water has been applied since 1980 and quality aspects are well described as well as the mineral composition and the specificity of these natural waters. Water is not only necessary for hydration but it can also be a vector of nutrition. It has been shown that some mineral waters can supply significant amounts of calcium, magnesium, and fluoride – sometimes too much for this element to be consumed daily as unique fluid intake – so that the composition of each of these waters has to be examined to best suit the consumer. While these mineral waters are protected in their bottles, tap water is distributed through hundreds of kilometers of pipes in large cities. It is thus difficult to ensure a good quality at the end of the line, particularly due to the formation of biofilms of bacteria which can develop when chlorine level is too low. There are some large cities which distribute water without any specific antibacterial treatment but as soon as there is a proliferation of bacteria they are obliged to treat the water. These treatments also affect the taste of the water. There are also different tastes of bottled waters due to their various mineral compositions.

Dr. Burckhardt: You forgot one of the most important pathogenic mechanisms of dehydration, which is the doctors. The number of cases of drug-induced dehydration that we get in our hospital is astonishing. The greatest successes I have had in recent years as a doctor have been from stopping the drug treatment that was causing dehydration. You say that we have inadequate clinical parameters for assessing hydration; I say, just give us one that works! There are several that do work – you mentioned bioelectrical impedance, and we need better statistics in relation to osmolarity. What about osmolarity? Does it work as a measurement tool?
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**Dr. Arnaud:** In many individual cases osmolarity can give false results when dietary intakes are not controlled. Methods for measuring urine density are also unreliable because diuresis can be increased inducing dehydration. The availability of measurement tools is thus an important practical problem and the development of rapid and reliable methods should be a research priority.

**Dr. Kehayias:** I think there is a possibility of developing a reliable device to measure hydration. Just as carbon to oxygen will give you fatness, so carbon to hydrogen will give you dryness. You could measure something of that sort *in vivo*. In your paper to the *New York Academy of Sciences*, you showed evidence of an expanded extracellular space in elderly patients who were clinically unwell [2]. Were those data supported by bioelectrical impedance measurements?

**Dr. Arnaud:** Yes. The results obtained in this study with oxygen-18, bromide and bioelectric impedance converged. We are presently studying a large group of the French population, of all age groups, to expand these data.

**References**