Supplement Article

Acute and chronic effects of hydration status on health

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Maintenance of fluid and electrolyte balance is essential to healthy living as dehydration and fluid overload are associated with morbidity and mortality. This review presents the current evidence for the impact of hydration status on health. The Web of Science, MEDLINE, PubMed, and Google Scholar databases were searched using relevant terms. Randomized controlled trials and large cohort studies published during the 20 years preceding February 2014 were selected. Older articles were included if the topic was not covered by more recent work. Studies show an association between hydration status and disease. However, in many cases, there is insufficient or inconsistent evidence to draw firm conclusions. Dehydration has been linked with urological, gastrointestinal, circulatory, and neurological disorders. Fluid overload has been linked with cardiopulmonary disorders, hyponatremia, edema, gastrointestinal dysfunction, and postoperative complications. There is a growing body of evidence that links states of fluid imbalance and disease. However, in some cases, the evidence is largely associative and lacks consistency, and the number of randomized trials is limited.

INTRODUCTION

Maintenance of fluid and electrolyte balance is essential to healthy living and is particularly important in periods of ill health. Dehydration, overhydration, and salt and water overload have been associated with morbidity and mortality, with older adults being at increased risk.[1–3] Warren et al.[1] reported a 17%, 30-day mortality in older patients with a principal diagnosis of dehydration, per the International Classification of Diseases, 9th Revision, with the 1-year mortality rate approaching 50%. Moreover, a heat wave that affected France in 2003 resulted in a 142% increase in mortality in Paris.[4,5] Most deaths occurred in vulnerable groups and resulted from heat-related illnesses, including dehydration.[4] Overhydration, particularly in individuals susceptible to water retention, is reported most commonly as a consequence of iatrogenic salt and water overload[2,6] but has also been seen in endurance athletes.[7]

At the cellular level, minor changes in cellular water content result in significant alterations in cell metabolism and function, mediated by changes in cell volume.[8,9] Cell swelling stimulates protein and glycogen synthesis, and cell shrinkage stimulates proteolysis and glycogen breakdown, with both pathways leading to the production of osmotically more active substances.[9] There is also evidence supporting the effects of cell volume on gene and protein expression, such as heat shock protein expression and antidiuretic hormone (ADH) stimulated by cell shrinkage.[8] In view of this and other reports linking fluid imbalance and disease, the European Food Safety Authority recommends a daily fluid intake of 2.5 L for men and 2.0 L for women to maintain urinary osmolarity of 500 mOsmol/L.[10] However, these guidelines[10] are based on limited evidence.

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This narrative review of the published scientific literature presents the current evidence base for the impact of hydration status on human health.

SEARCH STRATEGY

The Web of Science, MEDLINE, PubMed, and Google Scholar databases were searched for relevant studies published during the 20 years preceding February 2014 using the following terms along with the Boolean operators "AND" and "OR": hydration, dehydration, overhydration, fluid overload, fluids, and disease. The titles of the publications that resulted from the search were reviewed initially. If they were deemed suitable, then the abstracts were reviewed and, if suitable, the full manuscripts were reviewed. Human studies and studies with clinically relevant outcomes were preferentially selected; animal studies were also eligible for inclusion when human data ware not available.

Randomized controlled trials and large cohort studies were selected preferentially; other relevant studies were also eligible for inclusion when the preferred study types were not available. The bibliographies of extracted papers were searched for relevant publications. Older articles identified in this manner were included if the topic was not covered by more recent work.

DEHYDRATION

A state of dehydration occurs with excess loss of total body water and is often associated with electrolyte abnormalities, particularly dysnatremias. Hypertonic dehydration occurs when proportionally more water than sodium is lost from the extracellular fluid compartment. This may occur, e.g., as a result of age-related thirst impairment, which is seen in older adults. Hypotonic dehydration, on the other hand, occurs when the proportion of sodium lost is greater than the proportion of water lost. This may occur with the use of diuretics or in burn victims. Isotonic dehydration results from proportionate loss of water and sodium, and results in normal serum sodium concentrations. This may occur as a result of diarrhea, where there is salt and water loss in equivalent proportions. Common causes of isotonic, hypotonic, and hypertonic dehydration are listed in Table 1. The level of evidence[11] for the effect of hydration status on disease states is summarized in Table 2.

Table 1 **Common causes of isotonic, hypotonic, and hypertonic dehydration**

Type of dehydration	Cause
Isotonic	Burns
	Vomiting[a]
	Diarrhea[a]
	Ascites
Hypotonic	Vomiting[a]
	Diarrhea[a]
	Enterocutaneous fistula[a]
	Adrenocortical deficiency
	Renal failure
	Cerebral salt wasting
	Hyperglycemia
	Osmotic diuretics, Mannitol[a]
Hypertonic	Inadequate water intake
	Sweating
	Diabetes insipidus
	Polyuric phase post-acute tubular necrosis
	Osmotic diuretics, Mannitol[a]
	Loop diuretics
	Enterocutaneous fistula[a]
	Osmotic laxatives
	Tachypnea

[a]Depending on electrolytes lost.

UROLOGICAL DISORDERS

Urinary tract infections

Urinary tract infections (UTIs) are considered the most common bacterial infections and can result in permanent renal scarring in up to 60% of affected children.[12,13] The evidence linking hydration status to UTIs is far from conclusive.[14] Increased fluid consumption results in increased urine output and reduced serum and urine osmolality. Animal models have demonstrated that in the proximal urinary tract, high urine volume and flow reduces the antimicrobial load; low urine osmolality provides a more favorable environment for immune cell activity and, therefore, may be protective against pyelonephritis.[14,15] However, in the distal urinary tract, concentrated urine with high osmolality may be a protective factor and does not favor bacterial growth in the lower urinary tract.[16–18] Roberts et al.[19] demonstrated that diuresis and increased voiding frequency significantly reduced the bacterial count in female patients with proven lower UTI, although other studies have found no significant difference.[14,20]

Studies investigating the effects of increased fluid consumption on UTI have also reported conflicting results. Nygaard and Linder[21] reported that half of the 791 female teachers studied avoided drinking during work and were at a 2.2-fold increased risk of UTI. Eckford et al.[22] showed that increased fluid consumption may reduce the risk of UTI in women with a recent history of at least 2 idiopathic infections. In this crossover study, half of the participants were encouraged to consume water, aiming for a urine specific gravity of <1.015 for 4 months before crossover. The authors reported a significant reduction in incidence of UTIs in the group who measured their urine-specific gravity. Pitt[23] also demonstrated that the self-reported fluid consumption of patients with a history of UTIs was half

Table 2 **Summary of the evidence linking dehydration and overhydration to health disorders**

Health disorder	Summary of findings	Level of evidence[a]
Urological		
UTIs	Inconsistent findings; however, evidence largely favors the positive effects of "adequate" fluid intake on UTIs	IIb
Urolithiasis	Evidence largely from epidemiological studies and RCTs reporting beneficial effects of increased fluid consumption in preventing urolithiasis recurrence	Ib
Chronic kidney disease	One population-based cross-sectional study showed reduced risk of developing chronic kidney disease associated with increased fluid consumption	IV
Bladder cancer	Conflicting evidence on the link between chronic dehydration and bladder cancer	III
Gastrointestinal		
Functional constipation	Some evidence to suggest dehydration is a cause of functional constipation. The strongest evidence favors increased fluid consumption to treat constipation during a state of dehydration and as an adjunct to a high-fiber diet	III
Colorectal cancer	Evidence largely from retrospective case-control studies showing an inverse relationship between increased water consumption and colorectal cancer. The beneficial effects are greater for distal tumors	III
Circulatory		
DVT	Limited number of studies. Serum hyperosmolality associated with increased risk of DVT in hospitalized patients with stroke	III
Cerebral infarct	Limited evidence directly linking dehydration as a cause of cerebral infarct; however, some evidence linking serum hyperosmolality to poor outcome following stroke	III
CHD	Strongest evidence from a large prospective cohort study that reported that increased water consumption was inversely associated with reduced risk of fatal CHD events	IIb
Orthostatic hypotension	Good evidence linking dehydration and orthostatic hypotension, particularly in severe cases that result in significant hypovolemia	IIb
MVP	Limited evidence showing that acute mild dehydration induced MVP in healthy individuals and resolved with rehydration	III
Neurological		
Delirium	Evidence linking dehydration to cognitive impairment is inconsistent. An inverse relationship has been reported between increased water consumption and delirium in residents of long-term care facilities	III
Headache	No direct link between dehydration as a cause of headache. Evidence supports increased water consumption to help limit the intensity of migraines	IIb
Metabolic disorders		
Diabetes mellitus	Evidence from a cohort study suggests an inverse relationship between increased water consumption and type II diabetes. Strongest evidence supports the link between dehydration and poor clinical outcome with diabetic ketoacidosis	III
Obesity	Inconsistent evidence linking increased water consumption in relation to meals to treat obesity. Some evidence supports the effects of consuming cold water on increased basal metabolic rate	III
Respiratory disorders	Evidence suggests that dehydration in the airways may result in bronchoconstriction, and inspiration of humidified air has been shown to be beneficial in obstructive airway disease. However, no link between total body fluid balance and bronchoconstriction has been found	III
Pregnancy, labor, and breastfeeding		
Oligohydramnios	Good evidence from multiple RCTs and systematic reviews concluding that dehydration results in a reduced amniotic fluid index, which increases with rehydration	Ib
Labor	Good evidence from multiple RCTs and systematic reviews concluding that 250 mL/h of intravenous fluid results in reduced frequency of prolonged labor in fasted women. However, when patients ate and drank liberally, no clear differences were observed	IIb
Breastfeeding	Limited evidence suggesting that dehydration does not affect the quality or quantity of breast milk	IV
Other conditions		
Dental disorders, hypertension, gallstones, and breast cancer	Limited evidence to suggest that dehydration can predispose to dental disorders, hypertension, gallstones, and breast cancer	IV

(continued)

Table 2 **Continued**

Health disorder	Summary of findings	Level of evidence[a]
Iatrogenic fluid overload		
Bowel dysfunction in surgical patients	Strong evidence supports the link between fluid overload and poor postoperative outcome, including increased morbidity, length of hospital stay, and mortality. Meta-analysis reported that a state of fluid balance reduced postoperative morbidity and mortality	Ib
DVT	Some cohort studies have demonstrated increased risk of postoperative DVT associated with fluid overload	III
Overhydration in athletes	Links between overhydration and hypernatremia in athletes. However, a direct relationship remains to be demonstrated	III

[a]Level of evidence (based on the Oxford Centre for Evidence Based Medicine, 2009)[11]: Ia, systematic reviews (SRs) of RCTs with homogeneity; Ib, individual RCT with narrow confidence interval and >80% follow-up; IIa, SR of cohort studies with homogeneity; IIb, low-quality RCTs and large cohort studies; III, SR of case-control studies with homogeneity or individual case-control studies; IV, case series and poor cohort and case-control studies; V, expert opinion.
Abbreviations: CHD, coronary heart disease; DVT, deep vein thrombosis; MVP, mitral valve prolapse; RCT, randomized controlled trial; UTI, urinary tract infection.

that of the control group (2 glasses/day vs 4 glasses/day). Others have failed to report significant differences in self-reported fluid consumption between UTI patients and controls.[24,25]

Despite the inconsistent evidence, some expert committees recommend increased fluid intake in patients with UTIs as a measure of prophylaxis as well as treatment, particularly in children with recurrent infections.[26]

Urolithiasis

Urolithiasis occurs in up to 10% of the population, with a lifetime recurrence rate of up to 80%.[27] Currently, there is good evidence supporting the link between chronic dehydration and urolithiasis.[28] A study of healthy volunteers demonstrated that consumption of an additional 1.3 L of fluid was associated with reduced risk of crystallization.[28] Increased water intake and associated urinary dilution also resulted in a marked reduction in lithogenic salts.[29] Furthermore, epidemiological studies have shown an association between dehydration and urolithiasis, with a higher incidence being reported in hot climates and during summer months.[30,31] This association was further supported by a retrospective cohort study of steelworkers. The study compared the incidence of urolithiasis in hot-area workers with the incidence in those working at room temperature.[32] This study demonstrated that there was a greater prevalence of urolithiasis in those working in hot areas, with those working at high temperatures having a 9-fold increased risk of urolithiasis.[32] Other large population studies have reported that increased fluid intake was inversely associated with stone formation.[33] The strongest evidence, however, shows that increased fluid consumption reduces the risk of stone recurrence.[34] Borghi et al.[34] randomized patients following the development of their first stone to receive a higher intake of water, aiming for a urine output of more than 2 L/day (group 1), or to receive no intervention (a control group, group 2). The authors reported a significant reduction in the recurrence rates of urolithiasis (12.1% in group 1 vs 27.0% in group 2) and increased time to recurrence in the intervention group (38.7 ± 13.2 months in group 1 vs 25.1 ± 16.4 months in group 2).[34]

Given the evidence, international guidelines currently recommend increased fluid intake to produce 2–3 L of urine per day as a prophylactic measure for recurrent urolithiasis.[27,35]

Chronic kidney disease

Chronic kidney disease (CKD) is a progressive condition that leads to fibrosis and scarring of the kidney. Dehydration resulting in increased serum osmolality stimulates the release of ADH from the hypothalamus, increasing water reabsorption in the kidney. ADH also results in peripheral vasoconstriction and renal blood flow redistribution, which may lead to progression of existing CKD.[36] It is also proposed that maintaining a state of euhydration reduces plasma ADH and is, therefore, protective against renal damage.

Studies looking into the role of increased fluid intake and CKD are inconsistent. Some researchers have reported a protective role of increased urine output on the rate of decline in estimated glomerular filtration rate.[37] Strippoli et al.[38] also demonstrated an inverse relationship between water intake and the risk of developing CKD, with those consuming 3.2 L of fluid a day being at lower risk than those who consumed 1.8 L/day (odds ratio [OR], 0.5; 95% confidence interval [CI], 0.32–0.77). However, other researchers have reported increased renal function loss with increased urine volume production in individuals with established CKD.[39,40]

Bladder cancer

Bladder cancer is the seventh most common cancer in the United Kingdom, with an age-standardized 5-year survival rate of 58.2% for men and 50.2% for women.[41] There is conflicting evidence on the effects of increased fluid consumption on bladder cancer, with the body of evidence suggesting that there is no clear relationship.[42–44] The urogenous theory suggests that the development of bladder cancer is influenced by prolonged exposure to carcinogens in the urine.[45] The theory suggests that increased fluid consumption results in increased urine dilution and voiding frequency, leading to reduced carcinogen contact time with the bladder wall.[46] This is supported by experiments in dogs in which known human bladder carcinogens were administered.[47] The authors reported that increased voiding frequency resulted in a significant reduction in urothelial DNA adducts, likely due to reduced contact time with the carcinogen.[47]

Several studies have demonstrated an inverse relationship between increased fluid consumption and increased urinary frequency, particularly nocturia and bladder cancer.[48,49] However, others have reported an increased risk of bladder cancer in association with increased fluid consumption.[42,43] In many of these studies, however, the increased risks of bladder cancer are attributed to other beverages (tea, coffee, alcohol) or tap water with high chloride content, but not bottled water.[42,50,51]

GASTROINTESTINAL DISORDERS

Functional constipation

Constipation is characterized by the passage of infrequent hard stools. Fluid balance is thought to be necessary to maintain stable bowel function, although the evidence is inconsistent. There are reported associations between a chronic state of dehydration and constipation, especially in the elderly.[52] It is postulated that in a state of dehydration, there is increased fluid absorption from the stool, which may lead to hard stool and reduced stool output. Moreover, adequate hydration is considered to be important in stool consistency and maintaining bowel motility.[53]

A randomized crossover study in healthy male volunteers demonstrated that low fluid intake may be an etiological factor in chronic constipation.[54] The study participants were prescribed standardized nutritional and physical activity and randomized to 0.5 L or 2.5 L of fluid per day for 1 week followed by a crossover after a 2-week washout period. The authors demonstrated that during the period of fluid restriction, there was a significant reduction in stool weight and frequency as well as an increased tendency toward constipation. Moreover, bowel function returned to normal when the fluid-restricted group returned to normal fluid consumption. However, the authors did not report any differences in bowel transit time.[54] There is also evidence suggesting that increased water consumption enhances the effects of a high-fiber diet on stool frequency and reduces laxative consumption in adult patients with functional constipation.[55] In addition, increased water consumption has also been shown to improve bowel function in children who use osmotic laxatives for functional constipation.[56] Others, however, have shown no effect of increased fluid consumption on constipation.[57]

Although many clinicians and clinical guidelines recommend increasing fluid consumption for the treatment of constipation, the evidence is clear only in the case of patients with both constipation and dehydration.[58]

Colorectal cancer

Colorectal cancer is the third most common cancer in the United Kingdom, with a 50% 5-year survival rate.[59] There is limited evidence supporting the theory that increased water consumption reduces the risk of colorectal cancers, particularly distal tumors. It is thought that increased fluid consumption may decrease bowel transit time and, therefore, limit the contact time of carcinogens with the bowel mucosa.[60] Animal models have demonstrated that increased bowel transit time and constipation are significant risk factors for colonic neoplasia due to prolonged contact time with carcinogens.[60] Shannon et al.,[61] in a retrospective case-control study, observed that increased water ingestion was inversely associated with the risk of colon cancer. The association was strongest among women who drank 5 or more glasses of water per day relative to those who drank 2 glasses of water per day (OR, 0.55; 95% CI, 0.31–0.99). Among men, the association was less marked (OR, 0.68; 95% CI, 0.38–1.22).[61] Other retrospective case-control studies have demonstrated a strong inverse dose–response relationship between increased water intake and rectal cancer among men after adjustment for other risk factors. However, no differences were observed in women in these studies.[62,63]

Gallstones

Gallstones affect 10%–15% of adults in the Western world and, although often asymptomatic, can cause serious health complications.[64] It is well reported that biliary stasis is a major risk factor for the development of gallstones.[65,66] Water consumption has been shown to induce gallbladder contraction and emptying.[67,68]

Yamamura et al.[68] demonstrated in healthy volunteers that 400 mL of water resulted in a gallbladder ejection fraction of 33.5 ± 4.2% 20 min after ingestion. Therefore, in theory, this may protect against gallstone formation.[69] However, a direct relationship has yet to be demonstrated, and further studies are needed.

CIRCULATORY DISORDERS

Dehydration has been shown to result in increased plasma viscosity, which is a risk factor for thrombogenesis.[70,71] Patients with underlying hematological disorders that predispose to hyperviscosity syndrome, such as myeloma and polycythemia, are, therefore, at increased risk.[72] Exercise-induced dehydration and hyperthermia have also been linked to mortality in sickle cell disease, thought to be a consequence of dehydration that triggers erythrocyte adhesion and vascular occlusion.[73,74] Other studies have reported that normal erythrocytes, when dehydrated, display adhesive properties similar to those seen in sickle cell disease.[74]

Deep vein thrombosis

Deep vein thrombosis (DVT) affects 1 in 1000 annually and can lead to pulmonary embolism, which can be life threatening.[75] There is limited evidence to support a direct link between dehydration and DVT. Markers of dehydration, including serum osmolality of >297 mOsm/kg and urea-to-creatinine ratio (mmol:mmol) >80, were shown to be associated with a significantly increased risk of DVT in hospitalized patients following an acute ischemic stroke.[76] Some studies have demonstrated that prehydration reduces plasma viscosity and may be protective against DVT associated with long airplane flights.[77]

There is insufficient evidence to conclude a strong association between dehydration and DVT; however, expert committees and national guidelines recognize dehydration as a risk factor.[75]

Cerebral infarct

Stroke is associated with morbidity and mortality, often with significant physical and psychosocial impact on the patient and his or her family. There is limited evidence linking dehydration to the development of stroke or indeed poor outcome after stroke. In theory, the risk of increased plasma viscosity associated with dehydration may predispose to stroke in a way that is similar to other thrombogenic conditions, particularly in patients with underlying atherosclerosis or those prone to hyperviscosity syndrome.[78,79] Tohgi et al.[79] reported that postmortem examinations of older adults revealed that high hematocrit values were associated with a higher risk of cerebral infarction in deep subcortical structures of the brain. The incidence in those with hematocrit values >51% was 9.6 times greater than that for patients with hematocrit values <30%.[79] Furthermore, it is important to note that a significant proportion of patients are at risk of ongoing dehydration following stroke, particularly in the presence of dysphagia.[75] Rodriguez et al.[80] also demonstrated in the THIRST (The Hydration Influence on the Risk of Stroke) study that patients admitted to the hospital with ischemic stroke had higher osmolarity than age- and gender-matched patients.

Some studies have also shown a link between markers of dehydration, including raised plasma osmolality and hematocrit, with increased risk of stroke morbidity and mortality.[81–83] Moreover, in patients with ischemic stroke, the best discharge outcome has been shown to be associated with an initial mid-range hematocrit value.[81–83]

Coronary heart disease

Coronary heart disease (CHD) is the most common cause of death in the United Kingdom.[84] There is limited evidence that links dehydration to CHD. Whole-blood viscosity and plasma viscosity are recognized risk factors for myocardial infarction and have been shown to increase with dehydration.[85]

Chan et al.,[85] in the prospective cohort Adventist Health Study, investigated the association between fatal CHD and intake of water and other beverages. Participants without known heart disease (8280 male and 12 017 female) were followed up for 6 years. The authors reported a significant relative risk reduction in fatal CHD events in participants who drank 5 or more glasses of water/day compared with those who drank 2 or fewer glasses. Other studies, however, have reported no association between increased fluid intake and CHD.[86] Jan et al.[87] demonstrated that in patients admitted to the hospital with myocardial infarction, high plasma viscosity on admission was associated with a higher incidence of complications. The authors also reported that 80% of the patients studied had a reduced fluid intake post myocardial infarction, predisposing them to dehydration.[87]

Orthostatic hypotension

Orthostatic or postural hypotension is defined as a decrease in systolic blood pressure of 20 mm Hg or a decrease in diastolic blood pressure of 10 mm Hg from the sitting or supine position to standing up. It results from an inadequate physiological response to postural changes in blood pressure. Volume depletion and

autonomic dysfunction are common causes of orthostatic hypotension, which can result in cerebral hypoperfusion and syncope.[88] Webber et al.[89] reported that dehydration was one of the most common causes of orthostatic hypotension and syncope in US Air Force trainees. Moreover, increased fluid consumption prior to blood donation has been shown to help relieve some of the presyncopal side effects.[90]

Adequate hydration is particularly important in older adults, where there is a high prevalence of falls, which often result in serious injury. Although there is limited evidence directly showing reduced risk of falls in response to increased fluid consumption, adequate hydration is recommended by healthcare professionals.[91]

MITRAL VALVE PROLAPSE

Mitral valve prolapse (MVP) is an abnormal bulging of 1 or both of the mitral valve leaflets into the left atrium during ventricular systole.[92] It is associated with decreased left ventricular volume.[93,94] Lax et al.[94] induced mild dehydration using 20 mg of furosemide in 10 healthy male volunteers with normal baseline echocardiograms, reporting MVP in 1 of 10 participants, which resolved with hydration.[94] However, in patients with preexisting MVP, the same group demonstrated no impact from ingesting 1 L of fluid.[95]

NEUROLOGICAL DISORDERS

Maintenance of a well-hydrated state is important to maintaining normal brain function. Dehydration has been linked to headache and cognitive impairment, although the evidence is inconclusive. Moreover, there is evidence linking dehydration to changes in brain morphology. Several studies have reported that acute dehydration resulted in increased ventricular size proportional to body weight loss.[96,97] Kempton et al.[96] also reported functional brain changes that were associated with acute dehydration in healthy adolescents. These findings are particularly relevant to patients with underlying neurological disorders.

Delirium

Delirium, a state of acute confusion, has also been linked to dehydration. There is inconsistent evidence from healthy volunteer studies demonstrating a link between dehydration and cognitive impairment. Dehydration of as little as 2% of total body weight is detrimental to physical, visuomotor, psychomotor, and cognitive performance.[98,99] Voyer et al.[100] reported an inverse relationship between water consumption and delirium in residents of long-term care facilities and showed that the risk of delirium is reduced by 33% with each additional glass of water consumed. Another study also showed that dehydration is a risk factor for delirium in hospitalized older adults.[101] Moreover, Lawlor et al.[102] investigated reversible causes of delirium in patients with advanced cancer and reported an association between dehydration and delirium reversibility. However, in the presence of other confounders, this failed to reach statistical significance.[101] In keeping with some of the evidence, national guidelines recommend adequate hydration in patients with delirium.[103]

Headache

Headache, which has many underlying causes, is one of the most common presentations to general practice physicians in the United Kingdom. There is inconsistent evidence linking dehydration as a cause of headache; however, there is stronger evidence indicating that increased fluid consumption may help relieve some forms of headache. Studies of healthy volunteer have demonstrated that water deprivation results in headache that resolves with rehydration.[104,105] Dehydration is also thought to cause postdialysis and alcohol consumption headache.[106–108]

In a study by Spigt et al.[109] in which 18 patients with headache were assigned either placebo medication or a 1.5-L increase in daily water intake, no significant differences were observed in the number of headache episodes; however, there was a reduction in headache intensity and duration. A more recent randomized controlled trial demonstrated that increased water consumption of 1.5 L/day in patients with a previous history of headache improved migraine-specific quality-of-life scores.[110] However, no significant changes were observed in headache frequency and duration.[110]

Despite the limited evidence, the British Association for the Study of Headache recommends that good hydration be maintained in patients with medication overuse headache and that intravenous fluid therapy be used to help treat patients with migraine.[111]

METABOLIC DISORDERS

Diabetes mellitus

Diabetes mellitus is a recognized risk factor for dehydration in the context of hyperglycemia, given the osmotic effects of glucose. Raised serum osmolality on admission has been shown to correlate with poor outcome in children admitted with diabetic ketoacidosis.[112] There is also some evidence highlighting a potential protective effect of increased water consumption on the development of hyperglycemia. Roussel et al.[113] tested

the fasting glucose of 3615 French men and women aged 30–65 years with a normal fasting glucose at baseline and followed up with them for 9 years. The authors reported an inverse association between water consumption and the development of new-onset hyperglycemia, despite accounting for known risk factors. However, it is difficult to isolate the effects of healthy behaviors that may correlate with increased water consumption.

Obesity

Obesity is associated with many comorbidities and is quickly becoming one of the most common causes of morbidity and mortality in the developed world.[114] It is postulated that increased water consumption before and/or during meals may help obese individuals by reducing their food intake. However, recent studies have highlighted that this regime may only work in selected individuals.[115–117] Vij et al.[118] demonstrated that consumption of 500 mL of water 3 times a day before meals in overweight girls resulted in a significant reduction in body mass index over an 8-week period. The authors attributed these findings to the thermogenic properties of water, reported to increase the basal metabolic rate by up to 30%.[119] Boschmann et al.[120] demonstrated in a randomized controlled crossover trial that water consumption of 500 mL in obese adults resulted in 24% increased energy expenditure. Dubnov-Raz et al.[121] also demonstrated an increase of 25% in energy expenditure in overweight children who drank 10 mL/kg of cold water. However, these effects are likely the result of cold beverage consumption rather than the water consumed.

RESPIRATORY DISORDERS

Fluid homeostasis within the lung parenchyma contributes to normal cell function and effective gas exchange.[122] In asthma, some studies have demonstrated a link between exercise-induced bronchoconstriction and inability to adequately humidify and warm large quantities of inspired air.[123] However, there is no evidence linking overall state of hydration and pulmonary disease directly.

PREGNANCY AND BREASTFEEDING

Physiological changes during pregnancy include increased total body water due to increased plasma volume.[124] Pregnancy is also associated with increased risks of UTI, constipation, and gallstone disease.[125] There is limited evidence supporting the benefit of adequate fluid intake on these conditions. Despite this, healthcare professionals generally advise pregnant women to ensure adequate hydration.

Oligohydramnios

There is good evidence to suggest that inadequate fluid balance may result in oligohydramnios, associated with increased fetal complications and poor perinatal outcome.[124,126] It is thought that increasing maternal hydration may induce fetal diuresis, leading to increased amniotic fluid volume.[127,128]

A randomized controlled trial investigating the effects of intravenous isotonic and hypotonic solution and oral water intake on the amniotic fluid index (AFI) in women with oligohydramnios reported that maternal hydration with intravenous hypotonic and oral water was associated with an increase in AFI as measured by ultrasound.[129] Similar findings were also demonstrated in a randomized controlled observer-blinded trial in women with oligohydramnios who drank an additional 2 L of water.[130] In a more recent study in women with normal amniotic fluid, the authors showed an increase in AFI of 16% following ingestion of 2 L of water and an 8% reduction in the fluid-restricted group who received 100 mL of water.[131] There is clearly good evidence showing a direct relationship between maternal hydration and amniotic fluid volume; however, these studies did not report on clinically relevant fetal or maternal outcomes.

Labor

There is inconsistent evidence on the benefits of maintaining a well-hydrated state during labor. Garite et al.[132] demonstrated improved outcomes during labor with increased intravenous fluid rates of 250 mL/h (group 1) in nulliparous women compared with the standard maintenance rate of 125 mL/h (group 2). Group 1 received, on average, 479 mL more fluid than group 2, and exhibited a significantly lower frequency of prolonged labor.[132] Eslamian et al.[133] also compared intravenous fluid rates of 250 mL/h and 125 mL/h during labor in a randomized double-blind study and showed shorter duration of labor and lower frequency of prolonged labor and oxytocin use in the group receiving 250 mL/h. The authors also reported trends toward lower frequency of cesarean section in the group receiving 250 mL/h, although this did not reach statistical significance.[133] Another study, however, failed to show any difference in labor outcomes with increased fluid intake.[134] Moreover, other studies investigating the impact of hydration in preterm labor failed to demonstrate any benefits of fluid therapy, except in women with evidence of dehydration.[135]

Breastfeeding

There are well-documented benefits of breastfeeding, both for the mother and the baby. Studies investigating the effect of fluid consumption or restriction on the quantity or quality of breast milk produced found no influence.[136,137] Nevertheless, the European Food Safety Authority recommends that breastfeeding women consume an additional 600–700 mL of fluid per hour.[10]

OTHER CONDITIONS

Dehydration has been linked with other conditions including hypertension, breast cancer, and dental disorders, although the evidence is limited.[138–140] There is, however, an association between low urine output and daytime hypertension in patients with diabetes.[139]

It is also thought that a state of chronic dehydration may predispose to dental disorders by reducing the production of saliva, which protects teeth.[138] Similarly, a small retrospective case-control study reported that patients with a diagnosis of breast cancer reported lower water intake compared with controls.[140]

HYDRATION STATUS AND DRUGS

Hydration status can have an impact on the pharmacodynamic and pharmacokinetic properties of medication.[141] An altered hydration state, particularly dehydration, has been shown to have an impact on kidney function[142] and can affect the safety and efficacy of some drugs, particularly those with a narrow therapeutic range, such as lithium. Commonly used drugs such as nonsteroidal antiinflammatory drugs (NSAIDs) can be particularly problematic due to lack of awareness of the renal interactions.[142] Gorski et al.[143] investigated the use NSAIDs among iron-man triathlon competitors and found that 60% of those questioned had used NSAIDs for pain relief in the last 3 months; however, less than a third of the cohort were aware of the potential renal complication of NSAIDs.[143]

It is also important to consider drugs such as diuretics and antihypertensives, which may alter the hydration status of individuals and increase their vulnerability to adverse events with heat stress and dehydration. Following the heat wave that affected France in 2003, there was a significant increase in the number of adverse drug reactions reported in association with drugs such as diuretics and angiotensin-converting enzyme inhibitors, among others.[144]

OVERHYDRATION AND FLUID OVERLOAD

Overhydration has also been linked with morbidity and mortality. Some psychiatric conditions predispose to excess fluid consumption, as seen in psychogenic polydipsia where individuals consume excess water, irrespective of osmolality. This can lead to significant consequences such as heart failure and urinary tract abnormalities.[145] Moreover, excess water consumption can cause hyponatremia, which is an independent risk factor for bone fractures.[146–148] This may be a result of reduced bone mineral density and increased risk of osteoporosis.[149]

Overhydration in athletes

Overhydration has also been reported to be detrimental in endurance athletes, with excess fluid consumption having been linked to exercise-associated hyponatremia (EAH). Severe EAH can cause cerebral edema and mortality. The incidence of EAH varies from 3% to 29%[7,150] in marathon runners, with most studies reporting excess fluid consumption as the main underlying risk factor.[7,151] This may be further exacerbated by other factors such as the concomitant use of NSAIDs, which are commonly used for pain relief.

Iatrogenic fluid overload

The most common cause of overhydration is iatrogenic fluid overload and overprescribing, most notably in hospitalized surgical patients. Fluid and electrolyte therapy comprise an essential part of perioperative care, and there is a narrow margin for safety.[152,153] The 1999 UK National Confidential Enquiry into perioperative deaths found that at the extremes of age, errors in fluid management, usually fluid excess, were the most common cause of avoidable postoperative morbidity and mortality.[6] Numerous studies have shown that inaccurate prescription of fluid results in fluid overload; some patients were reported to receive up to 5 L of excess water and 500 mmol of excess sodium (and chloride) per day.[154,155] This can result in heart failure, pulmonary edema, and renal impairment. Furthermore, a meta-analysis of randomized clinical trials of intravenous fluid therapy in major elective open-abdominal surgery reported a reduction in postoperative complications by 41% and length of hospital stay by 3.4 days in patients managed with appropriate (near zero) fluid balance as opposed to states of fluid imbalance.[153]

Fluid overload and bowel function in surgical patients

Postoperative complications such as intestinal ileus are a common cause of morbidity following gastrointestinal surgery. More serious complications such as the breakdown of bowel anastomosis can result in significant

morbidity and mortality. Intestinal edema has been shown to play a major role in postoperative gastrointestinal dysfunction.[156] Surgical trauma results in salt and water retention;[152] fluid excess in the perioperative period can lead to edema, not only in the peripheries but also in the gastrointestinal tract, lungs, myocardium, and periorbital tissues. Gastrointestinal edema is associated with anastomotic swelling,[156] an increase in abdominal pressure, reduced splanchnic blood flow, and renal perfusion and may, therefore, result in anastomotic dehiscence.[157] Schnuriger et al.[158] reported that the volume of intravenous crystalloids administered in the first 72 hours post primary colonic surgery following trauma significantly predicted anastomotic leak, with those receiving $\geq$10.5 L during this period at a 5-fold increased risk of anastomotic dehiscence.

Fluid overload and deep vein thrombosis in surgical patients

DVT is common in surgical patients due to immobilization, among other factors. Hydration status, particularly dehydration, is considered a risk factor due to increased plasma viscosity as discussed previously. Impaired coagulation has also been reported in the context of postoperative fluid overload.[159] Ruttman et al.[160] demonstrated that hemodilution was associated with increased coagulation. In a later study, the authors reported that hemodilution results in decreased activity of anticoagulant factors, therefore, predisposing to clot formation.[161] Janvrin et al.[162] randomized 60 patients admitted for elective laparotomy to receive either intravenous fluids during or after the operation or no intravenous fluids. The authors reported that patients receiving fluids were hemodiluted. Moreover, there was a significantly greater incidence of DVT in the group that received fluids compared with the group that did not, 30% vs 7%, respectively.[162]

Monitoring of fluid input and output in all patients is of great importance as knowledge of fluid balance can help direct adequate fluid replacement where needed.

CONCLUSION

Maintaining a normal state of hydration is important, as dehydration has been shown to be a risk factor for many health conditions. There is a growing body of evidence supporting the link between the state of fluid imbalance and disease. However, the evidence is largely associative and lacks consistency with a limited number of randomized trials.

One of the biggest challenges is achieving consistency in the way hydration, dehydration, and, indeed, overhydration are defined and measured. Many studies often rely on self-reported fluid consumption, which at times, has been shown to be inconsistent and inaccurate. This is perpetuated by the current lack of widely accepted screening tools or gold standard tests that allow for easily performable and replicable measurements of fluid balance. Given these challenges, further work is required to address these important issues.

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