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News and Views

Research Advances in Hydration Status and Kidney, Liver, and Cardiovascular Health, and Tailored Water Intake Recommendations for Chinese Children

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Abstract

Suboptimal hydration status has increasingly been recognized as a risk factor for the progression of chronic diseases. A nationwide survey conducted in China found that 82% of children aged 6 to 17 years failed to meet the recommended daily total water intake of 1600–2500 mL. On average, boys consumed 1603 ± 731 mL per day, while girls consumed 1487 ± 661 mL per day, placing them at a higher risk of dehydration. Worldwide studies have suggested associations between dehydration and chronic kidney disease, steatotic liver disease, and cardiovascular diseases in adults. However, there is a lack of evidence concerning hydration status and target organ damage in the pediatric population. Only a limited number of studies have suggested that suboptimal hydration status is associated with transient renal impairment, an increased risk of metabolic dysfunction-associated steatotic liver disease (MASLD), and decreased ventricular structure and function in children. This article reviews the association between hydration status and target organ damage in both adult and pediatric populations and summarizes tailored water intake recommendations for Chinese children. We aim to advance research on hydration status and kidney, liver, and cardiovascular health, especially in the pediatric population.

Keywords: hydration status; dehydration; target organ damage; kidney; liver; cardiovascular; healthy drinking recommendations

1. Introduction

Water is a vital nutrient required in large quantities and plays a critical role in human physiology, essential for growth, development, and overall health maintenance [1]. Body water percentage decreases with age, constituting approximately 80% of body weight in newborns, 70% in infants and toddlers, and gradually declining to 60–70% by the age of 12 [2]. Adequate water intake is essential for maintaining the osmotic pressure and electrolyte balance in the body, especially in regulating sodium (Na^+) and potassium (K^+) levels [3]. Additionally, water facilitates crucial biochemical processes (such as glycolysis, the citric acid cycle, and oxidative phosphorylation) in intracellular and extracellular environments, and helps preserve the structural integrity and functional efficiency of various tissues, organs, and systems [3]. Age- and sex-specific recommendations for adequate water intake have been developed by the World Health Organization (WHO), China, the United States, and the European Food Safety Authority [4]. Specifically, the daily total water intake (TWI) for boys aged 4–17 years ranged from 1.6 L to 3.3 L, while for girls it ranged from 1.6 L to 2.3 L [4]. Disruption in water balance, such as dehydration, can lead to organ dysfunction and even target organ damage due to oxidative stress and inflammatory responses triggered by the activation of the renin-angiotensin-aldosterone system (RAAS), arginine vasopressin (AVP), and the aldose reductase-fructokinase (AR-F) pathway [5–8]. Emerging evidence underscores the role of healthy lifestyles, including a balanced diet, sufficient physical activity, and adequate sleep, in preventing chronic non-communicable diseases and adverse health outcomes [9,10]. As an important component of healthy lifestyles, adequate water intake and optimal hydration status have garnered increasing attention regarding their impact on health [7,8].

This narrative review is conducted to summarize the studies on the association between hydration and various target organ damage in adults and children, and the tailored water intake recommendations for Chinese children. We aim to offer empirical evidence and practical guidance on the role of hydration status in promoting health and preventing chronic diseases. Current studies consistently identify suboptimal hydration status as a significant risk factor for target organ damage [11–13], as briefly summarized in Table 1 (Ref. [14–37]) and Fig. 1. However, studies on hy-

Table 1. Population-based evidence on hydration status and target organ damage.

Population	Study type	Hydration status assessment	Adverse health effects	Publication year
			Kidney	
Adult	Cross-sectional study	Total water intake	Decreased kidney function/chronic kidney disease [14]	2013
Adult	Cross-sectional study	Weight change	Decreased kidney function [15]	2015
Adult	Cohort study	Serum sodium	Decreased kidney function/chronic kidney disease [16]	2017
Adult	Experimental study	Weight change	Decreased kidney function/kidney injury [17]	2018
Adult	Cohort study	Dehydration/weight change	Acute kidney injury [18]	2019
Adult	Cross-sectional study	Plasma osmolality	Urinary protein level/renal tissue fibrosis and sclerosis/end-stage kidney disease [19]	2020
Adult	Experimental study	Weight change	Kidney injury [20]	2021
Adult	Cohort study	Serum creatinine	Incident kidney injury [21]	2022
Pediatric	Cohort study	Urine specific gravity	Elevated urinary protein/transient renal impairment [22–24]	2022, 2024
			Liver	
Adult	Crossover study	Weight change	Decreased liver function [25]	2001
Adult	Cross-sectional study	Plasma copeptin	Liver steatosis and hepatitis [26]	2019
Adult	Experimental study	Inferior vena cava to aorta cross-sectional area ratio (IVC/Ao)	Liver tissue changes [27]	2021
Pediatric	Cohort study	Urine specific gravity	Increased risk of incident MASLD [28]	2023
			Cardiovascular	
Adult	Observational study	Dehydration/weight change	Mitral valve prolapse [29,30]	1992, 1995
Adult	Cohort study	Daily water intake	Increased coronary heart disease risk [31]	2002
Adult	Observational study	Serum osmolality	Increased risk of venous thromboembolism [32]	2004
Adult	Cohort study	Serum sodium	Increased coronary heart disease risk [33]	2015
Adult	Observational study	Weight change	Reduced stroke volume/cardiac output [34]	2020
Adult	Experimental study	Weight change	Myocardial structural changes [35]	2020
Adult	Meta-analysis	Total water intake	Decreased cardiovascular performance [36]	2023
Pediatric	Observational study	Weight change	Decreased ventricular structure and function [37]	2011

Abbreviations: MASLD, metabolic dysfunction-associated steatotic liver disease.

dration status and health remain limited, particularly in the pediatric population. Large-sample population studies are needed utilizing adequate water intake interventions and accurate measurements of hydration status and adverse health outcomes to inform causal inferences.

2. Population Studies on the Association Between Hydration Status and Target Organ Damage

2.1 Association Between Hydration Status and Kidney Damage

Recent studies underscored the importance of hydration status on kidney function and health. In the adult population, data from the 2005–2006 National Health and Nutrition Examination Survey (NHANES) indicated an association between low water intake and chronic kidney disease (CKD), suggesting a protective role of adequate water intake in maintaining kidney health [14]. A cross-sectional study conducted in Central America among 189 sugarcane workers found that repeated dehydration can lead to kidney damage, as indicated by 14% of participants exhibiting decreased kidney function (estimated glomerular filtration rate [eGFR] <60 mL/min) [15]. In Japan, a retrospective cohort study identified elevated serum sodium level as an independent risk factor for CKD, with each 5 mmol/L increase in sodium associated with an 18% higher risk of CKD [16]. Another retrospective study involving Japanese patients with primary glomerular disease observed an association between elevated plasma osmolality and an increased risk of end-stage kidney disease, with every 5 mOsm/kg increase accounting for a 1.56-fold rise in risk [19]. A trial study in the Netherlands compared the effects of acute versus prolonged exercise and dehydration on eGFR and kidney damage in healthy males and observed that either prolonged exercise or dehydration led to a decline in eGFR and an increase in kidney injury biomarkers [17]. Additionally, a prospective multi-center cohort study involving 905 patients with acute kidney injury across 15 countries showed that dehydration, shock, and the use of nephrotoxic drugs were the most common causes of acute kidney injury [18]. In the United Kingdom, a study investigating controlled hydration status during high-intensity interval running found that dehydration can increase serum and urine osmolality, as well as con-

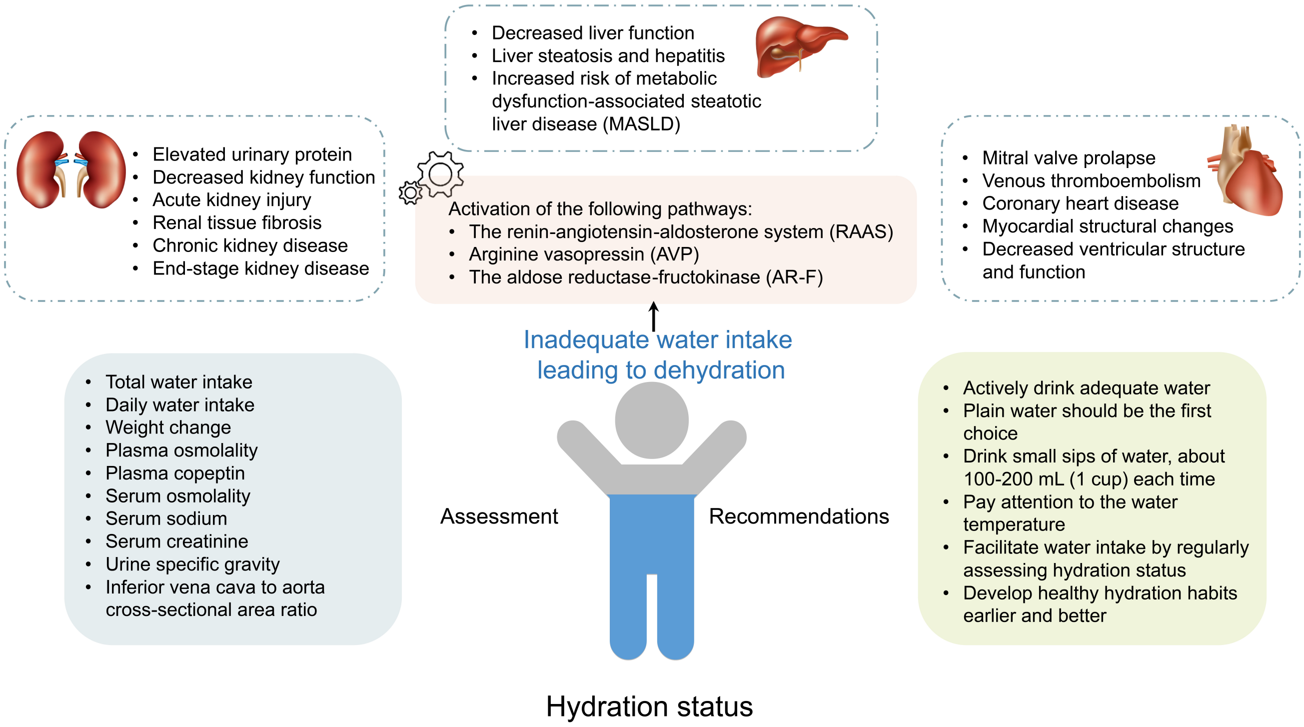

Fig. 1. Hydration status assessment, risks and mechanisms of dehydration-associated kidney, liver, and cardiovascular damage, and water intake recommendations.

centrations of osmolality-corrected urinary kidney injury molecule-1 (uKIM-1), suggesting that dehydration exacerbated damage to the proximal renal tubules [20]. A study in Costa Rica reported that field workers were more susceptible to dehydration compared to other workers, showing a higher incidence of low eGFR (26% vs. 7%) and kidney injury (26% vs. 2%) [21]. In the pediatric population, a cohort (the PROC) study in China reported that children with dehydration showed elevated urinary protein and an increased risk of transient renal impairment [22], and further identified the interactions between hydration status and physical activity/ sleep duration on kidney health [23,24]. In summary, these studies emphasize the adverse impact of dehydration on kidney health, including an increased risk of acute kidney injury and CKD, and the progression to end-stage kidney disease.

2.2 Association Between Hydration Status and Liver Damage

Several population studies examined the impact of hydration status on liver and metabolic health. In the adult population, a crossover study conducted in Denmark on the acute effects of moderate dehydration in healthy adult males found that dehydration led to a 25% reduction in functional hepatic nitrogen clearance and impaired urea synthesis [25]. In Italy, a cross-sectional study compared plasma copeptin levels among obese individuals with and without non-alcoholic fatty liver disease (NAFLD) and healthy non-obese individuals, reporting that obese NAFLD patients had significantly higher plasma copeptin levels, which positively correlated with the severity of hepatic steatosis, lobular inflammation, and non-alcoholic steatohepatitis [26]. In the United Kingdom, an experimental study involving twelve healthy adults observed that suboptimal hydration status (assessed by the inferior vena cava to aorta cross-sectional area ratio) shortened liver T1 relaxation time measured via liver tissue imaging [27]. In the pediatric population, the PROC study suggested that suboptimal hydration status may increase the risk of incident metabolic dysfunction-associated steatotic liver disease (MASLD, updated definition of NAFLD in 2023). The study observed that children transitioning from euhydration to dehydration or consistent with dehydration presented higher incidence rates of MASLD over a 4.5-year follow-up period [28]. In summary, these studies underscore the importance of maintaining optimal hydration status for liver health and highlight the risks associated with dehydration, including impaired urea synthesis, and the development and progression of liver diseases such as MASLD.

2.3 Association Between Hydration Status and Cardiovascular Damage

Extensive research conducted over decades has consistently demonstrated the significant impact of hydration status on cardiovascular health. In the adult population, two early studies observed that mild dehydration induced by furosemide led to mitral valve prolapse, and prolapse-associated murmurs or echocardiographic changes improved upon rehydration, highlighting the impact of dehydration on cardiac structure [29,30]. Another large-scale prospective cohort study in the United States involving 20,297 participants without pre-existing heart disease, stroke, or diabetes found that higher water intake (5 glasses or more, 240 mL/glass) was associated with a decreased risk of fatal coronary heart disease [31]. In the United Kingdom, a prospective observational study involving 102 patients with acute ischemic stroke found that elevated serum osmolality, urea levels, and the urea-to-creatinine ratio after stroke were associated with an increased risk of venous thromboembolism [32]. A community-based prospective cohort study in the United States, involving 12,779 participants, found a positive association between serum sodium concentration and the ten-year risk of coronary heart disease [33]. Furthermore, an interventional trial involving 12 healthy adult males reported no significant changes in cardiovascular function indicators after exercise under various hydration conditions, indicating limited impact of exercise or dehydration on myocardial contractility or function [38]. However, a similar study in the United Kingdom observed that dehydration reduced stroke volume and cardiac output during exercise due to impaired cardiac filling and venous return, rather than affecting left ventricular function [34]. In Germany, an observational study among healthy adults found that dehydration significantly reduced myocardial T1 and T2 relaxation times, suggesting that hydration status affects myocardial structure [35]. A meta-analysis on hydration status in relation to heart rate, heart rate variability, and blood pressure during exercise found that optimal hydration reduced exercise-induced heart rate increases and improved heart rate variability after exercise [36]. In the pediatric population, a study involving Iranian adolescent wrestlers showed that a 3.4% weight loss due to dehydration affected cardiac structure and function, evidenced by changes in electrocardiogram and echocardiogram parameters [37]. In summary, these studies emphasize the association between dehydration and cardiovascular structural changes, and the increased risk of cardiovascular diseases.

3. Tailored Water Intake Recommendations for Chinese Children

Optimal hydration status is crucial for maintaining physiological functions and health, and adequate water intake recommendations have been established by the WHO, the United States, and the European Union [4]. In China, water intake recommendations for adult and pediatric populations have been outlined in the *Chinese Dietary Reference Intakes*, both in 2013 and the updated version in 2023 [39,40]. Despite these guidelines, inadequate water intake remains common among children and adolescents. A national survey on Chinese children's drinking behavior reported that the average TWI for boys aged 6 to 17 years was 1603 ± 731 mL/day, while for girls it was 1487 ± 661 mL/day, with plain water comprising about 51% of the TWI. Moreover, 82% of Chinese children do not meet the TWI recommendation: 1.6 L to 2.5 L for boys and 1.6 L to 2.2 L for girls aged 6–17 years [41]. The prevalent suboptimal hydration status in the pediatric population underscores the urgent need for targeted guidance and interventions to promote healthy drinking habits and prevent dehydration-related health consequences. Here, we highlighted the water intake recommendations for Chinese children.

3.1 Recommendation 1: Actively Drink Adequate Water by Age and Sex

According to China's dietary guidelines, the adequate intake (AI) of total water, including water from beverages and water from food, varies by age and sex: for children aged 6–11 years, it is 1800 mL/day (with 1000 mL drinking water from beverages); for adolescents aged 12–14 years, the AI is 2300 mL/day for males and 2000 mL/day for females, with drinking water contributing 1300 mL/day and 1100 mL/day, respectively; and for those aged 15–17 years, the AI increases to 2500 mL/day for males and 2200 mL/day for females, with 1400 mL/day and 1200 mL/day from drinking water, respectively.

3.2 Recommendation 2: Plain Water Should Be the First Choice

Plain water refers to various types of drinking water, including tap water, filtered and purified water, boiled water, bottled water, packaged drinking water, natural mineral water, and spring water. Unlike sugar-sweetened beverages, plain water contains no calories or artificial additives such as colorants, flavorings, or preservatives. It is affordable and easily absorbed by the body, ensuring efficient hydration without the need for complex metabolic processing. In contrast, sugar-sweetened beverages and caffeinated drinks contain complex components that may slow absorption and even promote fluid loss, potentially worsening dehydration. Thus, children were not recommended to drink sugar-sweetened, caffeinated (especially those under 12) and non-caloric sweetened beverages.

3.3 Recommendation 3: Drink Small Sips of Water, about 100–200 mL (1 Cup) Each Time

Drinking small sips of water or drinking slowly allows the body to gradually absorb water. This approach helps to prevent the rapid intake of large amounts of fluid, which could lead to increased urine output, rapid fluid loss, electrolyte imbalances, and gastrointestinal stress.

3.4 Recommendation 4: Pay Attention to the Water Temperature, Ideally Between 10 °C and 40 °C

Drinking beverages above 65 °C can damage the esophageal mucosa. Additionally, drinking cold water, particularly ice-cold water, can cause sudden constriction of gastrointestinal blood vessels, which may lead to stomach spasms, abdominal pain, or even diarrhea.

3.5 Recommendation 5: Facilitate Water Intake by Regularly Assessing Hydration Status

Hydration status can be assessed by thirst level, urination frequency, urine volume, and urine color, allowing for timely water replenishment.

3.6 Recommendation 6: Develop Healthy Drinking Habits Earlier and Better

For the development of healthy drinking habits in children, parents should provide healthy drinking choices, set reminders for drinking water, and demonstrate proper drinking behavior. Schools should enhance water supply facilities, incorporate health education into the curriculum, and organize water-related activities. Effective communication between families and schools is essential for monitoring the hydration status of children.

4. Conclusion

Dehydration adversely impacts kidney, liver, and cardiovascular health in both adult and pediatric populations. Further research is needed for adequate water intake interventions, especially in children and adolescents. Targeted recommendations for children, including active and adequate water intake, healthy drinking habits, and hydration status monitoring, may contribute to preventing dehydration-related target organ damage and improve long-term health consequences.

Availability of Data and Materials

Not applicable.

Author Contributions

YH, ML, and DH designed the study. ML, BW, MG, HH, and JL performed the review. ML and BW drafted the first version of the manuscript. All authors contributed to interpreting and editing the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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