The efficacy of electrolyte beverage in maintaining hydration in healthy adults with fasting-induced dehydration: A randomized controlled crossover trial

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ABSTRACT

Background and Objectives: This study evaluated the efficacy of electrolyte-containing beverages (EB) and demineralized water (DW) in maintaining and restoring hydration status and electrolyte balance in healthy adults experiencing fasting-induced dehydration. **Methods and Study Design:** A randomized, crossover design was applied in 12 healthy men (age, 23.2±1.1 years; body mass index, 21.9±2.0 kg/m2). Participants performed 12 hours of fasting and 2 hours of fast-breaking during rainy season. Before fasting and during fast-breaking stages, participants consumed 500 mL of DW or EB with additional 100 mL of DW each. EB contained 21 mEq/L sodium and 6% total carbohydrates, while DW contained neither. Hydration status was assessed using body mass, blood, and urine parameters. **Results:** At pre-fasting, body weight, plasma volume, blood sodium levels, cumulative urine output, and fluid retention did not differ between groups. During fasting, the DW group showed greater weight loss than EB (p <0.05). Post fasting, body weight, plasma volume, and sodium were similar between groups, but EB exhibited lower cumulative urine output (1010 vs. 1300 mL; p <0.05) and higher fluid retention (15.7 ± 30.6% vs -8.0 ± 24.5%; p <0.05). At the end of fast-breaking stage, both groups restored body weight to pre-fasting levels. **Conclusions:** These findings suggest that EB support hydration by improving plasma volume and electrolyte balance during fasting and after fast-breaking. Future studies should examine the effects of greater fluid intake before and after fasting, assess fluid retention rate in the middle of fasting, and evaluate hydration response in different season.

Key Words: carbohydrates, sodium, fluid retention, dehydration, rehydration strategy

INTRODUCTION

Water accounts for approximately 50–60% of total body weight in adults.[1] Body water contains electrolytes, including sodium, potassium, calcium, and magnesium, which play a crucial role in maintaining fluid homeostasis and supporting physiological function.[2,3] Adequate hydration is fundamental for thermoregulation, nutrient transport, and metabolic processes, whereas falling short may cause dehydration.[4–7] Dehydration is a condition caused by loss of body water and electrolyte imbalances and could disrupt physiological homeostasis and adversely affect cognitive and aerobic performance.[8,9] To mitigate these risks, standard guidelines recommend daily water intake ranges from 2 to 2.7 L for adult women and 2.5 to 3.7 L for adult men, depending on activity levels, environmental conditions, and body composition.

Fasting is a common practice that involves abstaining from food and drink from dawn to sunset.[10] While fasting is associated with spiritual and health benefits, it also poses physiological challenges, particularly dehydration and electrolyte imbalance.[10] Research by Hardinsyah (2017) reported that approximately 75.5% of Indonesian people experience dehydration during the afternoon (12.00-13.00), increasing to 89.8% as the time for fast-breaking approaches (iftar).[11] The risk of dehydration is further exacerbated during hot seasons or among people engaged in physical activities, where sweat loss is elevated.[12,13] Fasting-induced dehydration presents a distinct physiological challenge compared to exercise-induced dehydration. While exercise triggers acute, short-term fluid loss through thermoregulatory sweating, fasting involves prolonged, voluntary fluid restriction without active sweating mechanisms.[14,17,18]

In recent years, consuming electrolyte-containing beverages (EB) has emerged as a potential strategy to mitigate the risk of dehydration. Several studies have demonstrated their efficacy in improving hydration status across various conditions, including outdoor labour,[13] sports,[14] dengue fever,[15] and travel.[16] Despite these promising outcomes, the effectiveness of EB in preventing and managing dehydration and electrolyte imbalance during fasting remains underexplored.

This study aims to evaluate the efficacy of EB and DW in maintaining and restoring hydration status and electrolyte balance among healthy adults experiencing fasting-induced dehydration for 12 hours (Indonesia fasting duration). This study focuses on the effects of EB and DW on water absorption, electrolyte absorption, and fluid retention throughout the fasting and fast-breaking stages. The assessment is conducted through body, blood, and urine parameters.

MATERIALS AND METHODS

Study design

This study employed a randomized, crossover trial design as presented in Figure 1. It was conducted from November to December 2023 during rainy seasons in the De Laia Inn, Malang, Indonesia. It comprised two intervention phases with a five-day washout period. Each intervention phase consisted of several stages, including pre-fasting, fasting, and fast-breaking.

Due to the limited data on fasting-induced dehydration and electrolyte beverage efficacy, the sample size was determined based on a pilot study. Following the methodology of a prior study,[19] a total of twelve subjects were involved in this study.

Subjects were randomly assigned to one of two sequences in a crossover design. Randomization was conducted using a computer-generated random number sequence with an equal allocation ratio (1:1). The randomization process was executed by an independent investigator who was not involved in subject recruitment or data collection. The allocation sequence was concealed from investigators.

The allocation sequence was concealed using sealed, opaque envelopes, which were opened by an independent investigator. This method ensured that the principal investigators did not influence group assignments.

The laboratory analyst responsible for blood withdrawal and the principal investigators conducting the intervention and data analysis remained blinded to subject allocation throughout the study to minimize bias.

Ethical statement

This study was conducted according to the guidelines laid down in the Declaration of Helsinki. All procedures involving human subjects were approved by the Medical Research Ethics Committee with ethics approval number 7671/UN10.F17.10.4/TU/2023. Written informed consent was obtained from all subjects.

Subjects

The inclusion criteria for subjects in this study were as follows (1) man and healthy; (2) aged 20–40 years; (3) with a body mass index (BMI) of 18.5–22.9 kg/m²; (4) total body water of 50%-65%; (5) engagement in daily light- or moderate-intensity activity; and (6) ability to fast for 12 hours without experiencing any adverse effects. Subjects were recruited online. Following on-site screening, individuals who met the inclusion and exclusion criteria were enrolled in the study

Subjects were excluded if they (1) used medications that could influence metabolism and (2) had a history of metabolic, cardiovascular, endocrine, renal diseases, acute or chronic illnesses that could interfere with the absorption, metabolism, or excretion of the investigational products.

Screening was conducted prior to study enrolment to ensure all subjects met the specified criteria. All subjects received detailed information about the study objectives, procedures, and potential risks. The procedure of subject enrolment and analysis was presented in Figure 2.

Investigational poducts

This study investigated the effects of two investigational products (IPs), DW and EB, on hydration status in subjects with fasting-induced dehydration. EB was used as the test beverage, while DW was used as a control.

The EB contained a mixture of carbohydrates and essential electrolytes, which are 6% of carbohydrates, 21 mEq/L of sodium (Na^{+}), 5 mEq/L of potassium (K^{+}), 1 mEq/L of calcium (Ca^{2+}), 0.5 mEq/L of magnesium (Mg^{2+}), 16 mEq/L of chloride (Cl^{-}), 10 mEq/L of citrate^{3-}, and 1 mEq/L of lactate^{-} (POCARI SWEAT, PT Amerta Indah Otsuka, Indonesia). In contrast, DW did not contain any carbohydrates and electrolytes.

Study methodology

The study procedure of intervention phase consisted of preparation, pre-fasting, fasting, and fast-breaking stages. According to previous studies, the five-day washout period was selected to allow complete recovery and minimize carryover effects, following hydration study protocols conducted before.[20,21] Several analyses were conducted to examine the hydration status of each subject during each stage and assess the efficacy of IPs as presented in Figure 3.

Preparation stage

Subjects arrived at the laboratory between 6:00 and 8:00 p.m. before the intervention day and stayed overnight. They did initial measurements, including physical examination, dietary patterns, and physical activity.

They consumed a standardized dinner between 8:30 and 9:00 p.m., providing 550 kcal with a macronutrient ratio of 50% carbohydrates, 20% protein, 30% fat, and 496.5 mg sodium. Following, the meal, subjects were allowed to consume water ad libitum. The volume of fluid ingested was measured.

Pre-fasting stage

On the morning of intervention day, subjects emptied their bladders. They reported their collected cumulative urine output and volumes of fluid ingested within a night. Then, initial body weight, blood, and urine samples were collected and measured within 1 hour. Subjects also engaged in a 10-minute stretching before sample collection to promote blood circulation.

Following the initial measurement, they consumed 100 mL of water and a standardized breakfast, providing balanced nutrition with a 550 kcal which has a macronutrient ratio of 50% carbohydrates, 20% protein, 30% fat, and 496.5 mg sodium. In the end of preparation stage, subjects drank 500 mL of IPs.

Fasting stage

Subjects fasted for 12 hours, with consuming any foods or beverages strictly prohibited, and did light-intensity activity. In the middle of fasting, body weight was measured to monitor each subject's hydration status, while at the end of fasting, blood, urine, and body weight were measured. Throughout the fasting stage, urine output was collected.

Fast-breaking stage

Subjects consumed 100 mL of water, carbohydrate-rich snacks containing 150 kcal of energy per serving, and dinner meal, providing balanced nutrition with a 550 kcal which has a macronutrient ratio of 50% carbohydrates, 20% protein, 30% fat, and 496.5 mg sodium. Following the dinner meal, they consumed 500 mL of IPs.

Within 2 hours, subjects rested in a seated position. Then, last body weight, blood, and urine samples were collected and measured. Subjects also engaged in a 10-minute stretching before sample collection to promote blood circulation.

Laboratory analysis

The report of physical activity and dietary pattern of each subject were evaluated during preparation stage. Meanwhile, the hydration status of all subjects was monitored throughout the intervention phase, including pre-fasting, fasting, and fast-breaking stages. Several body, blood, and urine parameters were measured.

Physical activity

Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ). The outcome measures derived from IPAQ included (1) Metabolic Equivalent Task (MET) minutes per week and (2) minutes of self-reported moderate- and vigorous-intensity activity per week. Based on established values, physical activity data were converted into energy expenditure expressed as METs. In this study, walking or light-intensity activity was defined as <600 MET minutes/week, moderate-intensity activity as 600–3000 MET minutes/week, and vigorous-intensity activity as >3000 MET minutes/week.

Dietary pattern

Dietary pattern was measured using the Semi Quantitative-Food Frequency Questionnaire (SQ-FFQ).

Body measurement

Body weight was assessed using Body Fat Analyzer (Xiaomi XMTZC05HM, Anhui Huami Information Technology Co., Ltd, China). Body weight was measured once. Body weight change is an effective measure to monitor changes in hydration status.[20]

Blood analysis

Venous blood samples were analysed for serum sodium using the Ion-Selective Electrode (ISE) method (Architect C4100, ABBOTT, USA). Haemoglobin and haematocrit levels were measured via spectrophotometry (Cell-dyn Ruby, ABBOTT, USA). Each blood analysis was measured once.

The changes in plasma volume changes were calculated to assess the fluid absorption rate in the human body using the following DILL equation.[14,21]

ΔPV (%) = (PV post-PV pre)/(PV pre) = [(Hb pre x (1-HCTpost /100)) / (Hb post x (1-HCTpre/100)) - 100] * 100

where ΔPV = plasma volume changes; PV post = plasma volume after; PV pre = plasma volume before; Hb pre = haemoglobin before rehydration stage; Hb post = haemoglobin after; HCT pre = haematocrit before rehydration stage; HCT post = haematocrit after.

Urine analysis

Urine samples were collected to measure urine volume. The fluid retention rate was calculated using the following equation to evaluate the body's ability to retain fluids.[14]

FRR (%) = (100 (FI - Cumulative urine output)) / FI

where FRR = Fluid retention rate; FI = Fluid intake.

Statistical analysis

The results were presented as mean ± standard deviation (SD). Statistical comparisons between groups were performed using independent t-test. Statistical analysis among measurement time points in each group was performed using Repeated Measures ANOVA, followed by Least Significant Difference test. A *p*-value of <0.05 was considered statistically significant. All analyses were conducted using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Characteristics of subjects

This study included twelve healthy man subjects who completed each intervention phase. All subjects met the criteria, as presented in Table 1. One subject withdrew from the study and was excluded from the analysis due to concerns about the blood withdrawal process.

As presented in Table 2, IPAQ data showed the intensity of physical activity among subjects. Of the subjects, 5 engaged in light-intensity activity, while 7 reported moderate-intensity activity. No subjects were involved in vigorous-intensity activity. The detailed physical activity intensity data was presented in Table 2.

Dietary pattern of subjects

The dietary pattern of subjects before intervention was analysed through SQ-FFQ questionnaire. As presented in Table 3, the average daily energy intake of subjects was 1760 ± 344 kcal with a macronutrient composition consisting of protein 69.6 ± 26.0 g, fat 65.3 ± 21.2 g, and carbohydrates 223 ± 78 g. Subjects had a fibre intake of 9.3 ± 5.5 g and a water intake of 1890 ± 236 mL.

Body parameters

Body weight in both groups was measured throughout the intervention to calculate the percentage of body weight change, as presented in Table 4. The subjects' body weight was not different between EB and DW groups in pre-fasting stage. A significantly greater reduction in body weight was observed in the DW group during the middle of the fasting stage (0.8 ± 0.9%), whereas no reduction was observed in the EB group (p <0.05). At the end of the fasting stage, no significant difference in body weight loss was observed between the groups (1.2 ± 0.5%).

After the fast-breaking stage, body weight in both groups returned to levels comparable to the pre-fasting stage, with no significant difference between groups. The EB and DW groups showed increases in body weight of 1.4 ± 0.5% and 2.4 ± 2.9%, respectively.

Body fluid and electrolyte replenishment

In fast-breaking stage, two types of IPs, including DW and EB, were evaluated for their efficacy profile in replenishing fluids and restoring electrolyte balance following fasting-induced dehydration. The efficacy of these beverages in promoting rehydration was assessed by measuring several blood parameters, including plasma volume changes and blood sodium levels.

Changes in plasma volume

As presented in Figure 4, the plasma volume changes were not different between the groups in pre-fasting stage. After fasting stage, plasma volume increased in both groups.

After fast-breaking stage, EB and DW groups exhibited plasma volume changes, measuring 4.7 ± 7.8 % and 2.9 ± 5.7 %, respectively.

Changes in electrolyte

Both groups exhibited similar sodium levels in pre-fasting stage, as presented in Figure 5. After fasting stage, blood sodium levels increased to 139 ± 1.1 mmol/L in the DW group and 139 ± 1.7 mmol/L in the EB group, with no significant differences observed between the groups.

Although blood sodium was higher in EB group (139 ± 2.3 mmol/L) than in DW group (138 ± 1.3 mmol/L) after fast-breaking stage, no significant difference was observed.

Body fluid retention

In fast-breaking stage, two types of IPs, including DW and EB, were evaluated for their efficacy profile in retaining body fluid following fasting-induced dehydration. The efficacy of these beverages in maintaining fluid balance was assessed by measuring several urine parameters, including cumulative urine output and fluid retention rate.

Cumulative urine output

As presented in Figure 6, total fluid intake and cumulative urine output throughout the intervention were measured after fast-breaking stage. Within 14 hours of fasting and fast-breaking stages, EB group has lower cumulative urine output, measuring 1012 mL, compared to 1296 mL for DW group (p <0.05). The cumulative urine output in DW group is higher than its fluid intake, which is 1200 mL.

Fluid retention rate

Fluid retention rate was significantly higher in EB group (15.7 ± 30.6 %) compared to DW group throughout the fasting and fast-breaking stages (p <0.05), as presented in Figure 7. In contrast, DW group exhibited a negative fluid balance, measuring -8.0 ± 24.5 %.

No adverse events or harms were reported during the study. All subjects completed the intervention without experiencing any significant side effects or health complications related to the consumption of the investigational products, DW and EB.

DISCUSSION

This study aimed to evaluate the efficacy of EB and DW in enhancing hydration status as a strategy to prevent dehydration during fasting, particularly in maintaining and improving hydration status and electrolyte balance during fasting and the fast-breaking stages.

In this study, dietary assessments revealed that subjects consumed an average of 1887.4 ± 235.9 mL of water per day as their daily fluid consumption. This intake was below the Recommended Dietary Allowance, which suggests a daily water consumption of 2500 mL.[24] This finding suggests that participants already had low fluid consumption pattern prior to fasting.

Previous research has shown that individuals often fail to meet their hydration needs during fasting, consuming approximately 1670 mL of fluids per day, which may heighten the risk of dehydration due to restricted fluid intake.8 Mild dehydration, defined as a 1% to 2% loss in body weight, has been associated with impaired cognitive and physical performance because of disrupted homeostatic functions.[25–27] Due to the difficulty of people fulfilling their daily water needs, this study highlighted the importance of exploring alternative beverages that can enhance hydration status as a strategy to prevent dehydration during fasting.

According to the physical characteristics data, all subjects met the inclusion criteria and were classified as healthy people. The physical activity data revealed that subjects predominantly engaged in light- to moderate-intensity activities. These activities included walking, active commuting, and household tasks.[28] Thus, this study underscores the importance of investigating hydration and rehydration strategies in people performing daily activities rather than focusing on athletes during fasting.

This study employed a combination of assessment methods to improve the accuracy of its findings across the fasting and fast-breaking stages. The simultaneous measurement of blood parameters, urine output, and body composition provided a comprehensive evaluation of hydration status. A study by Santoso et al. identified the main indicators of hydration status, including changes in body weight, plasma volume, and urine output.[1]

In this study, the DW group exhibited significantly greater body weight loss than the EB group in the middle of the fasting stage. This finding suggests that although both groups consumed a standardized breakfast with identical fluid volumes, beverage composition influenced hydration status during fasting. Furthermore, consuming EB during pre-fasting stage appeared to mitigate the early onset of dehydration, which typically emerges within the 6 hours of fasting. While plain water is commonly consumed before fasting (8), our findings highlight the potential benefit of electrolyte beverages in maintaining hydration status. This finding aligns with a study by Castillo et al., which demonstrated that consuming sodium-containing beverages helps prevent body weight loss exceeding 2%.[27]

At the end of the fasting period, participants in both the DW and EB groups experienced mild dehydration, indicated by approximately 1.2% body weight loss after 12 hours of fasting. The physiological mechanisms of dehydration differ between fasting and exercise conditions. Unlike exercise-induced dehydration, which stems from acute thermoregulatory sweating during physical exertion,[27] fasting-induced dehydration is continuously influenced by baseline insensible water loss (IWL), the unperceived, automatic fluid loss through respiratory exhalation and skin evaporation occurring at rest.[17,18] During a 12-hour resting fast, an adult naturally expends approximately 300–400 mL of fluid through IWL alone, regardless of beverage type.[3]

A previous study has shown that moderate-intensity exercise at ambient temperatures of 28–30 °C for 1.5 hours can induce moderate dehydration, 2–3% body weight loss, due to fluid loss through sweating and thermoregulatory responses.[29] These findings suggest that dehydration severity is influenced by the nature and intensity of the activity. During fasting, dehydration risk is mainly driven by restricted fluid intake. In this study, the 600 mL of fluid intake at breakfast may have been insufficient to maintain optimal hydration status during the fasting stage.

To ensure an effective strategy for improving hydration status during fast-breaking stage, an appropriate fluid intake volume should be considered. In this study, subjects in both groups consumed 600 mL of beverages. This protocol adopted the recommended drinking pattern from a previous study, which stated 500 mL of beverage during fast-breaking stage.[8]

After fast-breaking stage, plasma volume remained stable in the EB group, whereas a decline was observed in the DW group. This finding is consistent with the study by Clarke et al., which demonstrated that sodium-containing beverages sustain higher plasma volume compared to water throughout the intervention.[30] This difference can be attributed to the electrolyte content of the beverage consumed by the EB group, particularly sodium and carbohydrates, which play critical roles in fluid absorption.

Sodium enhances fluid absorption from the small intestine into the vascular space, reducing fluid loss through excretion.[31] It creates an osmotic gradient that drives water movement across the intestinal epithelium, supporting plasma volume restoration.[27,32] Carbohydrates further support this process by promoting sodium-glucose co-transport, a mechanism that stimulates water uptake in the small intestine.[2] Elevated blood sodium levels reflect water retention within the vascular system, aiding in sustaining plasma volume. These combined effects of sodium and carbohydrate-containing beverages highlight their potential as effective oral rehydration solutions to counter fasting-induced dehydration. Clinically, maintaining plasma volume and blood sodium levels is essential to support vascular stability and prevent mild dehydration symptoms during the fast-breaking recovery.

In this study, EB group maintained stable blood sodium levels, whereas DW group experienced a decrease following the fast-breaking stage. Although blood sodium was higher in EB group than in DW group after fast-breaking stage, no significant difference was observed. While both groups consumed a standardized dinner with identical fluid volumes, this difference may be attributed to the absence of sodium in DW, which may influence fluid shifts from the intracellular to the extracellular space.[32] This finding is consistent with a study by Nainggolan et al., which demonstrated that consuming water was less effective in maintaining blood sodium levels compared to EB.[17] Sodium plays a crucial role in fluid balance by maintaining osmotic gradients and promoting water absorption.[32] A study by Ilyas et al. emphasized that maintaining water and electrolyte balance is essential for preserving cognitive and physical performance.[13] These findings highlight the critical role of beverage composition in influencing blood sodium levels during fast-breaking stage, highlighting the superior rehydration efficacy of EB compared to plain water.

While the sodium concentration in CE (21 mEq/L) is lower than standard WHO oral rehydration solutions (75 mEq/L) and may not maximally activate SGLT1-mediated cotransport, it is sufficient to support fluid absorption in mild fasting-induced dehydration. Furthermore, the superior fluid retention observed in the EB group is likely driven by renal conservation mechanisms; the presence of electrolytes and carbohydrates helps preserve serum osmolality, thereby mitigating sudden drops in aldosterone and arginine vasopressin and reducing excessive post-prandial diuresis.[2,36]

The decrease in plasma volume and blood sodium observed in the DW group was consistent with its lower fluid retention rate compared with the EB group. Accordingly, the DW group exhibited a negative fluid balance, whereas the EB group maintained a positive fluid balance. The higher fluid retention rate observed in EB group may be affected by the composition of the beverage. According to a study by Ronald et al., the Beverage Hydration Index (BHI) of EB is higher than water.33 The BHI reflects the hydration efficacy of beverages and serves as an indicator of fluid balance in the human body.[35] Notably, the BHI is affected by the sodium content of a beverage.30 However, it should be noted that standard BHI protocols evaluate hydration responses over a 4-hour period, whereas the present study applied a 2-hour fixed-volume observation post-fast-breaking. Therefore, while BHI cannot be directly generalized to this specific fasting context, our findings demonstrate a consistent physiological trend where sodium-containing beverages limit early diuresis and promote better short-term fluid retention.

The presence of electrolytes, sodium, enhances fluid retention by reducing diuresis. Sodium creates an osmotic gradient that promotes water absorption from the gastrointestinal tract into the bloodstream, thereby increasing plasma volume and limiting fluid loss through urine.[32] A previous study showed that isotonic solutions, which contain both electrolytes and carbohydrates, are more effective in promoting fluid retention compared to hypotonic solutions. This effect is attributed to the reduction in urine output following electrolyte consumption, aiding in sustaining hydration status.[35]

The findings of this study reinforce the negative correlation between fluid retention rate and cumulative urine output. The EB group, which consumed an electrolyte and carbohydrate-based beverage, exhibited lower cumulative urine output and a higher fluid retention rate compared to the DW group. These findings are consistent with a study by Chang et al., which demonstrated a negative correlation between cumulative urine output and fluid retention rate.[14] Thus, the composition of the beverage, specifically the presence of electrolytes and carbohydrates, plays a crucial role in optimizing fluid balance by enhancing fluid retention and mitigating excessive urine loss during rehydration.

These outcomes further support the significance of beverage composition in maintaining hydration status, particularly during fasting and fast-breaking stages. The ability of EB group to sustain plasma volume and blood sodium levels, coupled with reduced urine output and improved fluid retention, highlights the efficacy of electrolyte- and carbohydrate-containing beverages in promoting effective hydration and rehydration strategies. This study highlights the mechanisms of dehydration during fasting that primarily due to prolonged restriction of fluid intake. From a public health perspective, these findings carry substantial real-world relevance. Globally, over 1.5 billion Muslims practice intermittent fluid restriction during Ramadan, alongside a growing population engaging in therapeutic intermittent fasting, with a significant proportion experiencing mild-to-moderate hypohydration or inadequate fluid intake during fasting periods.[36]

From this study, we addressed the critical research gap regarding the under exploration of electrolyte beverage efficacy in fasting by providing novel insights into hydration responses through a comprehensive evaluation of clinical and biochemical markers, including plasma volume shifts, blood sodium, urine output, and body composition. This study is among the first to use clinical and biochemical markers, such as plasma volume changes, blood sodium, urine output, and body composition, to evaluate hydration responses to electrolyte beverages during fasting.

This study has several limitations. Fluid intake before and after fasting was relatively low, and the intervention was conducted during the rainy season when sweat losses may be lower. These limitations may limit the ability to detect significant differences among beverages. In addition, fluid retention rate was not measured during the middle of fasting stage, limiting the interpretation of the correlation between body weight changes and fluid retention. Furthermore, the relatively small sample size and inclusion of only healthy young men may restrict the generalizability of these findings to other populations or clinical settings. The open-label design may also introduce behavioural bias despite the use of standardised intervention procedures.

Conclusions

Twelve hours of fasting during the rainy season induced approximately 1.2% loss of body mass, indicating mild dehydration in healthy adults. Selecting an appropriate beverage before fasting and during the fast-breaking stage is important to support and improve hydration status. This study compared the efficacy of DW and EB on hydration-related parameters during the fasting and fast-breaking stages following fasting-induced dehydration.

DW exhibited a greater reduction in body weight during the middle of the fasting stage; however, both DW and EB resulted in similar body weight loss at the end of the fasting stage. Following the fast-breaking stage, EB demonstrated higher fluid retention and lower cumulative urine output compared with DW. Additionally, EB maintained more stable plasma volume and blood sodium levels after fast-breaking, whereas DW showed a decline in these parameters. These differences are attributed to the different sodium and carbohydrate content between these beverages.

Overall, these findings suggest that beverages containing electrolytes and carbohydrates may enhance fluid retention and support hydration recovery following fasting. Future studies should investigate the effects of greater fluid intake before and after fasting, assess fluid retention in the middle of fasting, and evaluate hydration responses under different environmental conditions.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The authors declare no conflict of interest. R.P. and D.R. are employees of PT Amerta Indah Otsuka.

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Table 1. Physical characteristics of subjects

Physical characteristics (n = 12)	Mean ± SD
1. Age (years old)	23.2 ± 1.1
2. Body weight (kg)	62.0 ± 7.3
3. Body height (cm)	168 ± 6.9
4. Body mass index (kg/m²)	21.9 ± 2.0
5. Total body water (%)	57.5 ± 3.0

Table 2. Characteristics of physical activity of subjects

Physical activity intensity based on IPAQ	IPAQ (MET min/week)	Total
Walking intensity	378	5 (42%)
Moderate intensity	1700	7 (58%)
Vigorous intensity	N.A.	N.A.

Values were shown as means±SD.

Table 3. Dietary pattern of subjects

Intake	Mean ± SD
Energy (kcal)	1760 ± 344
Protein (g)	69.6 ± 26.0
Fat (g)	65.3 ± 21.2
Carbohydrate (g)	223.2 ± 78.0
Dietary fibre (g)	9.3 ± 5.5
Water (mL)	1890 ± 236

Values were shown as means±SD.

Table 4. Body weight (BW) loss and gain[†]

Groups[‡]	Pre-fasting	Fasting				Fast-breaking	
		Middle of Fasting		End of Fasting			
	BW (kg)	BW (kg)	BW loss (%)	BW (kg)	BW loss (%)	BW (kg)	BW gain (%)
DW	62.1 ± 7.7[‡]	61.6 ± 7.5[§]	0.8 ± 0.9[¶]	61.4 ± 7.7[§]	1.2 ± 0.5[¶]	62.2 ± 7.6[‡]	1.4 ± 0.5[††]
EB	60.2 ± 7.6[‡]	60.2 ± 7.5[‡]	0.0 ± 0.5[††]	59.6 ± 7.6[§]	1.2 ± 0.5[¶]	61.0 ± 7.2[‡]	2.4 ± 2.9[††]

DW: Demineralized Water group; EB: Electrolyte Beverage group
Data are expressed as mean ± SD.
[†]BW loss (%) from pre-fasting BW as baseline and BW gain (%) from end-of-fasting BW as baseline.
[‡§]Different footnotes within the same row indicate a significant difference throughout fasting and fast-breaking stages ($p < 0.05$).
[¶††]Different footnotes within the same column indicate a significant difference between groups ($p < 0.05$).

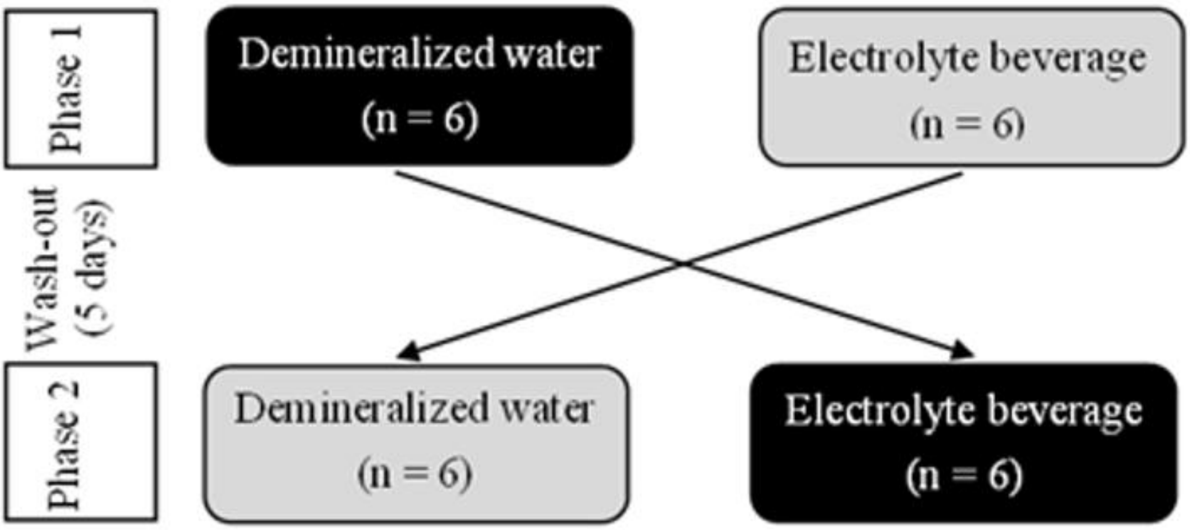


Figure 1. Study design. Black square is group 1; Grey square is group 2.

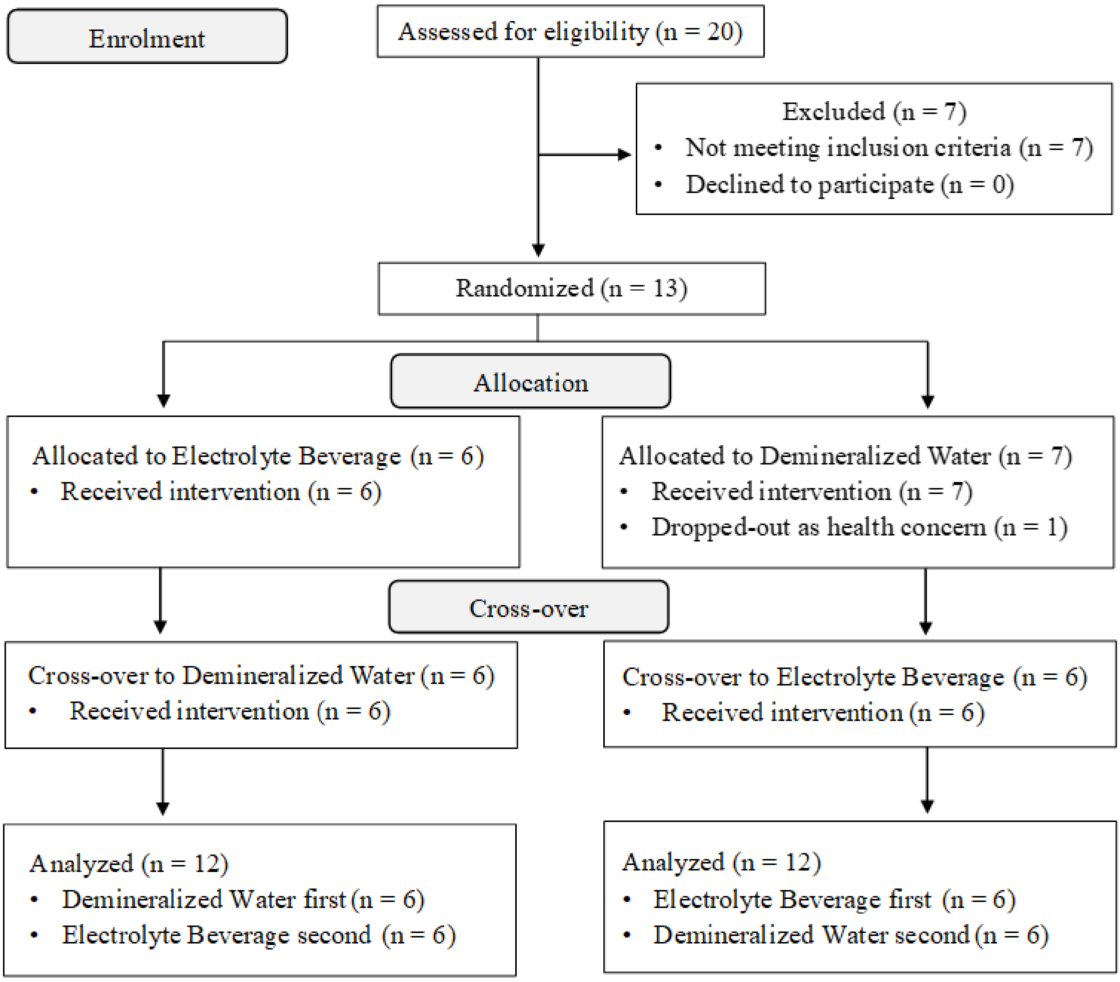


Figure 2. Consolidated Standards of Reporting Trials (CONSORT) flow diagram

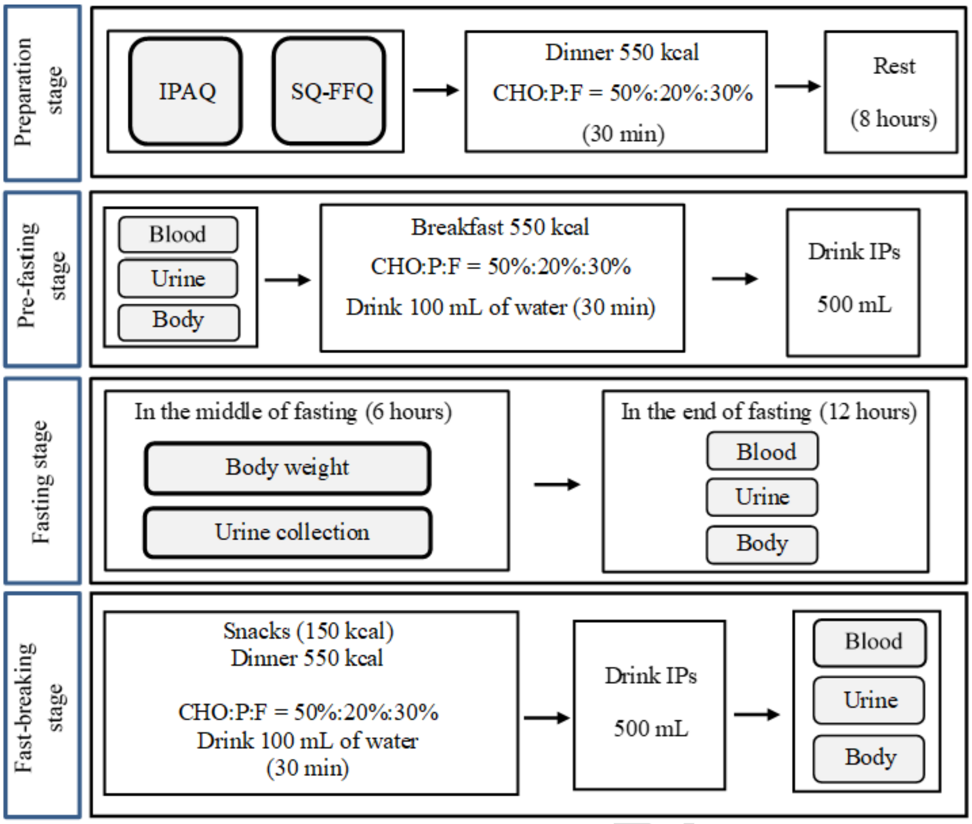


Figure 3. Study procedure on intervention day. The assessment of physical activity and dietary patterns were assessed through IPAQ and SQ-FFQ questionnaires. Nutritional intake and hydration were standardized throughout the intervention. Blood parameters were assessed and calculated, including haemoglobin, haematocrit, and blood sodium levels. The urine parameter was urine output, and the body parameter was body weight. CHO: Carbohydrate. P: Protein. F: Fat. IPs: Investigational Products (Electrolyte-containing Beverages/Demineralized Water)

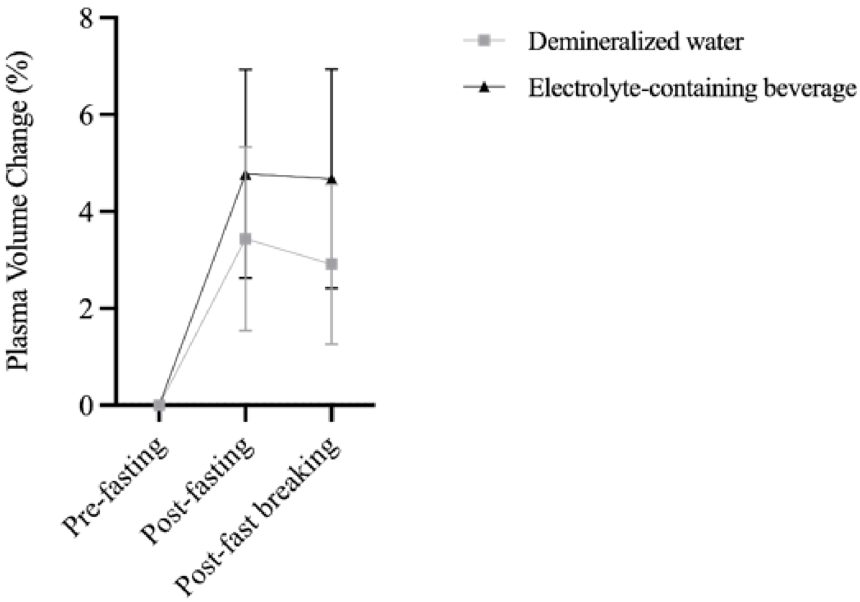


Figure 4. Time course of plasma volume changes with pre-fasting stage as baseline. Data are expressed as mean ± SE

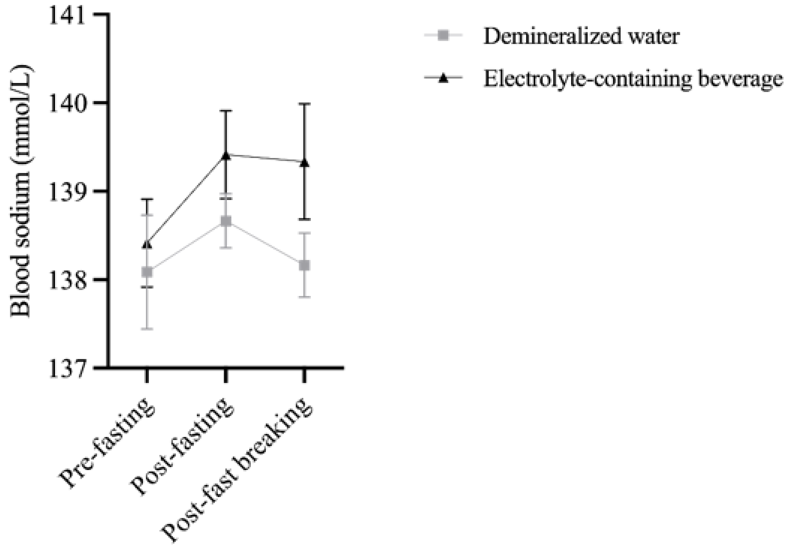


Figure 5. Time course of blood sodium level throughout the intervention phase. Data are expressed as mean ± SE

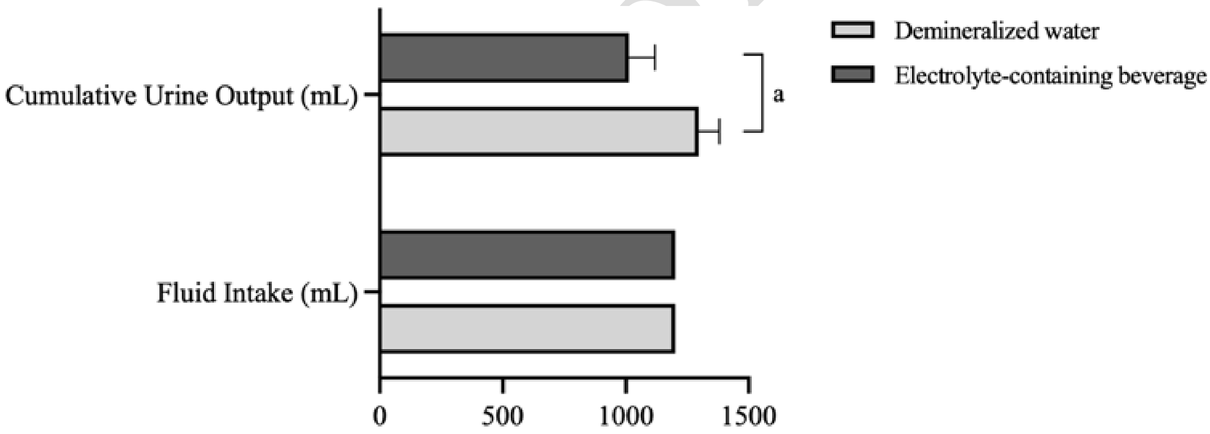


Figure 6. The difference in fluid intake and cumulative urine output between both groups within 14 hours of fasting and fast-breaking stages. Data are expressed as mean ± SE. †significant difference between groups ($p < 0.05$).

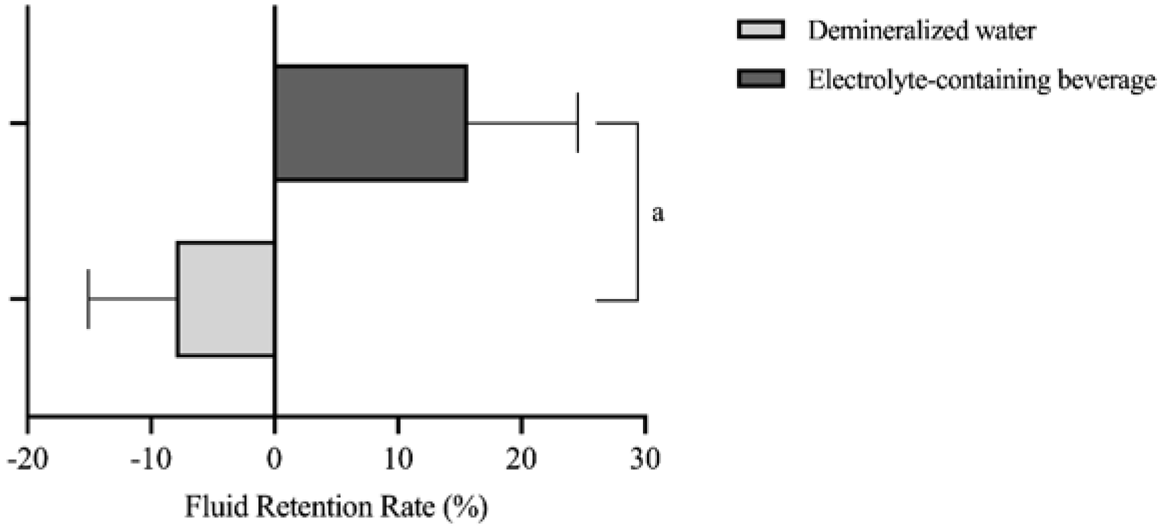
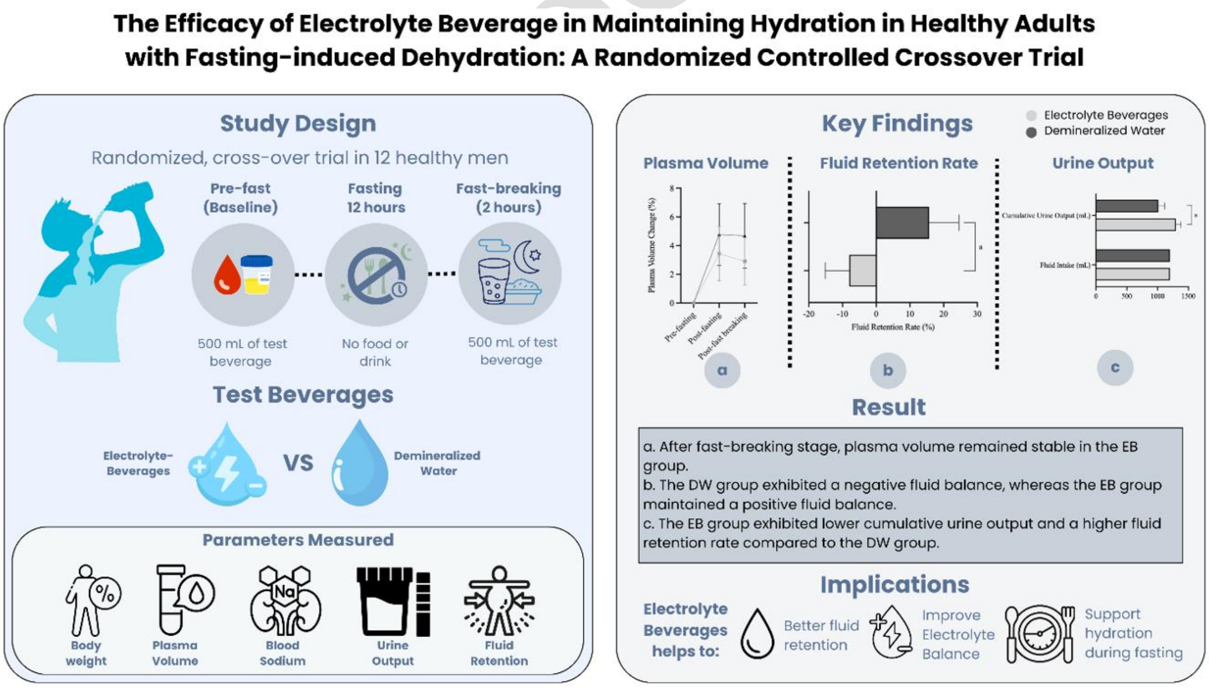


Figure 7. Fluid retention rate between both groups within 14 hours of fasting and fast-breaking stages. Data are expressed as mean ± SE. †significant difference between groups ($p < 0.05$).



Graphical abstract