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Systems Physiology: Fluid Balance

THE EFFECTS OF GLYCEROL INGESTION ON FLUID BALANCE AND CARDIOVASCULAR HEMODYNAMICS IN MALES DURING HYPOBARIC HYPOXIA

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ABSTRACT

Orri, JC, Robergs, RA, Lockner, DW, James, DS, Gibson, AL, Faria, E, Marks, DW, Weingart, H, Dalleck, L. The Effects of Glycerol Ingestion on Fluid Balance and Cardiovascular Hemodynamics in Males During Hypobaric Hypoxia. *JEPonline* 2007;10(3):1-13. Acute altitude exposure causes a loss of total body water and plasma volume. Glycerol ingestion has been shown to be rapidly absorbed by the intestine, leading to increases in serum osmolality, plasma osmolality, and total body water. The purpose of this study was to determine the effects of glycerol ingestion on fluid balance and cardiovascular hemodynamics at rest and during exercise during hypobaric hypoxia. Twelve men (33 ± 8 yr, 177 ± 3 cm, 75 ± 11 kg, 52 ± 10 ml $O_2 \bullet$ kg$^{-1} \bullet$ min^{-1}) each completed 4, 3.5 hr trials in a randomized design: (A) 6% carbohydrate/electrolyte drink at 1524 m, (B) 5% glycerol drink at 1524 m, (C) 6% carbohydrate/electrolyte at 3659 m, and (D) 5% glycerol at 3659 m. The

3659 m trials were 2 weeks apart. Subjects consumed 30 ml/kg lean body mass of each drink in 5 equal volumes at minutes 0, 30, 60, 90 and 120. Exercise intensity was 50% of the ventilatory threshold at 1524 m. Plasma volume change, free water clearance, osmolar clearance, and body mass change were measured every 30 min. Cardiac output was measured at min 0 and 150 during rest and cycling by CO_2 rebreathing. Glycerol ingestion (GLY) resulted in significantly lower free water clearance compared to carbohydrate/electrolyte (CHO) at min 90, 120, and 150 ($p < 0.05$) across altitude. Osmolar clearance was significantly higher for GLY vs CHO at min 60, 90, 120, and 150 ($p< 0.05$). No significant differences were found for plasma volume change, stroke volume, or heart rate. The body mass change and fluid retention were significantly higher for glycerol than for carbohydrate/electrolyte ($p< 0.05$). Even though a 5% glycerol solution offset the diuresis of acute hypobaric hypoxia, there did not appear to be any beneficial effects on cardiovascular hemodynamics.

Key Words: Cardiac Output, Free Water Clearance, Osmolar Clearance, Hyperhydration, Diuresis

INTRODUCTION

The challenges of high altitude activities such as climbing and skiing present circumstances of both reward and risk to the unprepared. Acute altitude exposure causes a loss of total body water (1) and plasma volume (PV) (2), accompanied by post-exercise increases in urine specific gravity (3). Two-fold increases in urine volume after exposure to 5,000 m have been reported (4), while nearly four-fold increases in urine output and decreases in both lower limb and forearm fluid volumes during ascent to 4,500 m have been found (5). In addition, reductions of 17% in stroke volume (SV) and cardiac output (Q) have been reported during exercise at 3,100 m (6) and 5,300 m (7).

Cardiovascular function and performance are dependent upon adequate hydration (8). Plasma volume has been shown to increase following the ingestion of glycerol and added water (9). The increases in PV have been shown to reduce the cardiovascular load by decreasing mean exercise and recovery heart rate (HR) (10,11). After ingestion, glycerol has been shown to be rapidly absorbed by the intestine, leading to increases in serum osmolality (12), plasma osmolality (13,14), and total body water (TBW) (15). Three hours after ingestion of glycerol, TBW has been shown to rise by 500 ml compared to water alone, with a reduced urine output at rest (16). The unique hyperhydrating property of glycerol is made possible by its ability to be distributed throughout the cells of the kidney, resulting in increased water reabsorption that is not possible with a carbohydrate solution (15).

At the present time, there are no known published studies investigating the influence of glycerol on fluid balance or cardiovascular parameters at altitude, although carbohydrate ingestion at altitude has been shown to improve performance when compared to a placebo (17). There is evidence to suggest that a research-based glycerol protocol would improve hydration and attenuate the decrease in PV that is experienced at altitude (15). Therefore, the purpose of this study was to determine the effects of glycerol ingestion on fluid balance and cardiovascular hemodynamics during hypobaric hypoxia. We hypothesized that glycerol ingestion would result in significantly lower free-water clearance (C_{H2O}) as well as higher osmolar clearance (C_{OSM}) values compared to carbohydrate ingestion. Additionally, we hypothesized that glycerol ingestion would result in significantly higher SV and Q, as well as decreased HR and plasma volume change (ΔPV), compared to carbohydrate alone.

METHODS

Subjects
Twelve male subjects volunteered to participate in this study. The subject group consisted of 6 competitive cyclists, 2 ultra-marathon runners, 1 elite marathoner, and 3 recreational athletes. Subjects needed to have resided in Albuquerque, NM (elevation 5,120 ft; 1524 m) for the past 6 months. In addition, a 4 week continuous stay, without exposure to altitudes greater than 3000 m within 3 days of the study was required. The mean data for the subject characteristics are presented in Table 1. The experimental procedures were approved by the Main Campus Institutional Review Board (IRB) and the Human Research Review Committee (HRRC) at The University of New Mexico School of Medicine. All subjects provided written informed consent.

Table 1. Descriptive data of the subjects.

Variable	Mean ± SD	Range
AGE (yr)	33 ± 8	21- 43
HT (cm)	176.6 ± 3.1	170.2 - 179.1
BM (kg)	75.2 ± 10.7	61.1 - 88.0
LBM (kg)	64.7 ± 6.9	56.4 - 75.9
BF (%)	13.4 ± 5.3	5.7 - 21.5
VO_2max (ml/kg/min)	51.9 ± 9.7	35.9 - 70.5
WORKLOAD* (W)	110 ± 26	75 - 163
DRINK VOLUME (ml)	1942 ± 208	1693 - 2278

BM, body mass; LBM, lean body mass; BF, % body fat from hydrodensitometry;
* = workload for all 4 trials. Drink volume was the same for all 4 trials.

Protocol
Hydration status was assessed during rest and exercise under the following 4 conditions: Trial A: 6% carbohydrate/electrolyte (CHO) ingestion at 1,524 m; Trial B: 5% glycerol + CHO ingestion (GLY) at 1,524 m; Trial C: CHO ingestion at 3659 m; and Trial D: GLY ingestion at 3659 m. The 4 trials took place at the Hyper/Hypobarometric Facility (altitude chamber) at the University of New Mexico. The protocol timeline is summarized in Table 2.

Table 2. Protocol timeline.

Time	Place	Data Collection	Condition
Pre-experimental	**Exercise Physiology Lab**	**Health history, consent, HT, BM, % B F**	----
		Max test (cycle ergometer)	
Pre-trial	**Outside the chamber**	**Urine osmolality, symptoms, water, catheter, electrodes**	----
Baseline	**Inside the chamber (no change in altitude)**	**Q, HR, SaO$_2$, blood,**	**Rest/exercise**
Minute 0		**BM, urine**	**Rest**
		Drink #1	**Rest**
Minute 30, 60, 90, 120	**At desired altitude**	**Blood, urine, BM, symptoms, drinks**	**Rest**
Minute150 Minute ~170	**At desired altitude**	**Blood, urine, BM, symptoms**	**Rest**
		Q, HR, SaO$_2$, blood	**Rest**
Minute ~190	**At desired altitude**	**Q, HR, SaO$_2$, blood**	**Exercise**
		Urine, BM, symptoms	**Rest**
Minute ~200	**Outside the chamber**	**END**	----

HT = height, BM = body mass, Q = cardiac output, SaO$_2$ = arterial oxygen saturation

Baseline Measurements: Pre-Trial

Lean body mass (LBM) was obtained through hydrostatic weighing at measured residual volume. Population-specific formulas were used for conversion of body density to % body fat (BF) (18). A maximal power output cycling test was conducted on a cycle ergometer (Lode BV, Groningen, Holland) using a ramp protocol with a starting load of 50 W for 2 min and increases of 25 W every min thereafter until failure to maintain a cycling cadence of 40 rpm. The ventilatory threshold (VT) was identified as the exercise intensity where the increase in minute ventilation (V$_E$) resulted in a nonlinear relationship between V$_E$/VO$_2$ and V$_E$/VCO$_2$ (19). Based on the linear decrement in VO$_2$max of ~9% for every 1,000 m, (19), an ~18% decrease was calculated for VO$_2$max at 3,659 m (12,000 ft). Assuming the same decrement in ventilatory threshold, the 3659 m VT was calculated to be ~82% % of the VT at 1524 m during pilot testing. For the subjects to cycle at steady-state during the 3659 m trials, 50% of the 1524 m VT was selected as the workload for the exercise component of each trial.

All participants were required to consume 40 ml/kg body mass (BM) of water during each of the 2 days preceding the trials. Also, to promote euhydration, they were asked to not ingest caffeine or other diuretics in the 48 hrs preceding each trial. Subjects were also asked to refrain from prolonged strenuous exercise (>60 min) for 24 hr prior to testing. In addition, they were to arrive at the altitude

facility after an 8 hr fast, with the exception of the ingestion of water and 2 cans of commercially available breakfast drinks 2 hr before testing (472 ml, 720 cal, 94 g CHO).

Data Collection at Altitude Chamber

Prior to data collection, the wet-bulb temperature and humidity in the Hyper/Hypobarometric Facility were determined with a sling psychrometer (Mercury C°, Bacharach Inc., Pittsburgh, PA). The mean temperature in the altitude chamber during testing was 22.8 ± 3.2 ° C with a relative humidity of 38.4 ± 11.5%.

Upon arrival to the altitude chamber, the subject provided a urine sample to verify baseline euhydration. A Teflon catheter was then placed in an antecubital vein and a baseline resting blood sample was obtained and immediately centrifuged (Marathon 21K/BR, Fischer Scientific, Pittsburgh, PA). The hemoglobin (Hb) concentration was determined in triplicate using the methemoglobin method (Spectronic 401, Milton Roy, Rochester, NY). Hematocrit (Hct) was determined in quadruplicate by microcentrifugation (International Micro-Capillary centrifuge, Model MB, Needham Hts., MA) and corrected for trapped plasma by multiplying by 0.96 (20). The plasma osmolality was measured by an osmometer (Advanced Instruments, Model 3D3, Norwood, MA). The ΔPV was determined from the method of Dill and Costill (20). The C_{osm} was calculated from the method described by Freund et al. (16), while C_{H2O} was calculated by: C_{H2O} = Urine flow rate- C_{osm}. Plasma and urine osmolality were determined through the freezing point method (21) using an osmometer (Advanced Instruments, Model 3D3, Norwood, MA).

Cardiovascular Measurements

Stroke volume (ml) was calculated by dividing Q by HR. Minute HR values were calculated by counting the number of R waves on the computer screen for 10 sec and multiplying by 6. Heart rate was also obtained by ECG integrated into the Rayfield software system (Rayfield Equipment, Waitsfield, VT).

The subject was connected via a mouthpiece to a combination 3- and 2-way Hans Rudolph valve (Kansas City, MO.) in preparation for measurement of Q. The subject breathed room air while wearing a noseclip as expired gases were collected for 4 min. Inspired air was measured by a low resistance flow meter (Rayfield Equipment, Waitsfield, VT) while expired air was directed to a mixing chamber and subsequently to gas analyzers (Erich Jaeger, Germany) for determination of F_EO_2 and F_ECO_2.

A 7 L bag (Hans Rudolph, Kansas City, MO) was vacuumed and filled with the following medically certified CO_2 concentrations (balance O_2): baseline and 1524 m rest = 10.0%, baseline and 1524 m exercise = 13.5%, 3659 m rest = 13.5%, 3659 m exercise = 15.0%. After steady state was attained, (~minute 4) the subject was switched over at end-tidal by closing the 2-way valve for 6-10 seconds of CO_2 rebreathing. The subject's breathing frequency was directed by the technician at a rate of 30-40 breaths/min. After equilibrium was established between the concentration of CO_2 in the bag, alveoli, and pulmonary capillaries, the 2-way valve was opened and the subject breathed room air again. After VCO_2 and respiratory exchange ratio returned to pre-rebreathing values (~minute 9), the maneuver was repeated to ensure reliability. If a plateau in PCO_2 was not established within 6-10 sec, a third rebreathing maneuver was performed. Heart rate (Hellige Servomed, Germany), and

percent oxygen saturation of Hb (Poet Criticare Systems, Inc, Ohio) were continuously recorded through integration with the Rayfield software system (Rayfield Equipment, Waitsfield, VT).

Cardiac output was calculated from the cardiovascular Fick equation (22):

Q ($l \cdot min^{-1}$) = VCO_2 (ml $\cdot min^{-1}$)/ (C_vCO_2- C_aCO_2) (ml $CO_2 \cdot l^{-1}$ blood), where C_vCO_2 = mixed venous blood CO_2 content and C_aCO_2 = arterial blood CO_2 content. The C_aCO_2 was calculated from a series of equations (22,23) after obtaining the peak mean end-tidal CO_2 values from 5 - 10 normal breaths. The % CO_2 at end tidal was calculated by a regression equation from known amounts of CO_2. The C_vCO_2 was determined after identification of a plateau in CO_2 during the rebreathing procedure and subsequent calculations of mixed venous blood PCO_2 (P_vCO_2) (22, 23). When SaO_2 was < 95% a correction for mixed venous and arterial CO_2 content difference (C_vCO_2- C_aCO_2) was calculated (23).

Immediately following the last resting rebreathing maneuver, the subject began pedaling at a workload corresponding to 50% of their VT at 1524 m. The same absolute workload was assigned at both altitude conditions. The CO_2 rebreathing procedure was performed in duplicate as described above. The exercise bout was sufficient to allow for 2 CO_2 rebreathing maneuvers preceded by stabilization of VCO_2 (~15-30 min). A baseline exercise blood sample was obtained between rebreathing maneuvers.

After determination of Q, the mouthpiece was removed, the subject dismounted from the bike; urine volume and nude BM were obtained. Urine volume, plasma and urine osmolality were obtained to calculate C_{osm} and C_{H2O}. Following these measurements, the assigned barometric pressure was attained via a pressure change equivalent of no more than 300 m/min (~ 7 min) for the 3659 m trial. Barometric pressure was confirmed by a hand-held barometer (Fisher Scientific, #02-406). In order to help blind the subject during the 1524 m trial, the chamber operator raised and lowered the pressure to simulate a 2000 m change (~ 7 min) prior to returning to 1524 m.

Glycerol Ingestion

During the barometric pressure change, the subject consumed the first drink (time 0). During the GLY trial ProHydrator (InterNutria Inc., Framingham, MA) was consumed as a 5% solution in a 50% diluted powdered CHO/electrolyte mix (Gatorade Co., Chicago, IL) plus water. Each subject consumed 30 ml/kg LBM of the solution in 5 equal volumes from a bottle at minutes 0, 30, 60, 90, and 120. The CHO drink was 30 ml/kg LBM of the carbohydrate/electrolyte drink only. Every 30 minutes, a blood sample, urine volume, and nude body BM were obtained, followed by drink ingestion. After all baseline measurements were repeated at min 150, the barometric pressure was returned to 630 mm Hg.

Statistical Analyses

Effect sizes were calculated on all DVs from previous studies which justified the use of 12 subjects. Calculated power was 0.8 (Statistica v6.0). Separate 3-way ANOVAs with repeated measures were performed for the cardiovascular and renal variables (SPSS v8.0 and Statistica v6.0). For all variables, the three repeated factors were altitude (1524 m, 3659 m) drink (CHO, GLY), and condition (time). The four cardiovascular dependent variables (DV) were Q, HR, ΔPV and SV at min 0 and 150. Exercise data are not included due to the variable exercise times for the subjects. For the renal variables, there were 5 levels of condition: 30, 60, 90, 120, and 150 min at rest. The 2 DVs were C_{osm}

(plasma osmolality) and C_{H2O}. Analysis of variance was performed on all DVs in order to determine significant differences in baseline hydration between trials. Statistical significance was set at $p < 0.05$. Data are presented as the mean $\pm$ SD.

RESULTS

All subjects completed all aspects of the protocol. There were no significant within-subject differences between baseline urine osmolality, plasma osmolality, Hct, Hb, Q, HR, and SV, verifying consistent intra-subject hydration levels for all 4 trials.

Cardiovascular Variables

There were no significant main effects or interactions for Q, HR, ΔPV, and SV ($p > 0.05$) (Tables 3-6). There was a significant main effect of altitude on HR ($p < 0.05$).

Table 3. Mean HR (bpm) values for CHO and GLY during rest and exercise at 1524 and 3659 m.

Drink	1524 m Rest	1524 m Exercise	3659 m Rest	3659 m Exercise
CHO	68.88 ± 13.24	112.79 ± 16.48	74.13 ± 11.99	125.29 ± 16.56
GLY	67.0 ± 7.5	110.33 ± 11.75	72.58 ± 13.83	122.29 ± 15.69

Table 4. Mean Q (L/min) values for CHO and GLY during rest and exercise at 1524 and 3659 m.

Drink	1524 m Rest	1524 m Exercise	3659 m Rest	3659 m Exercise
CHO	4.6 ± 1.06	14.49 ± 2.76	4.49 ± .090	16.85 ± 2.88
GLY	4.63 ± 0.92	14.55 ± 2.17	4.32 ± 0.79	17.25 ± 2.99

Table 5. Mean ΔPV (%) values for CHO and GLY during rest and exercise at 1524 and 3659 m.

Drink	1524 m Rest	1524 m Exercise	3659 m Rest	3659 m Exercise
CHO	7.73 ± 5.68	-4.91 ± 4.03	7.46 ± 5.92	-4.26 ± 4.93
GLY	12.62 ± 5.02	-1.04 ± 5.33	13.37 ± 6.64	-2.76 ± 5.11

Table 6. Mean SV (ml) values for CHO and GLY during rest and exercise at 1524 and 3659 m.

Drink	1524 m Rest	1524 m Exercise	3659 m Rest	3659 m Exercise
CHO	67.87 ± 15.65	130.65 ± 28.70	61.52 ± 13.19	134.98 ± 18.94
GLY	70.27 ± 15.57	133.78 ± 26.62	61.39 ± 14.47	141.69 ± 19.44

Renal Variables

The C_{H2O} and C_{OSM} results were pooled across altitude. A significant time x drink interaction was found for C_{H2O} ($p < 0.05$). The C_{H2O} was significantly lower for GLY compared to CHO at min 90, 120, and 150 ($p < 0.05$) (Figure 1). A significant time x drink interaction was also found for C_{OSM}. The C_{OSM} was significantly higher for GLY compared to CHO at min 60, 90, 120, and 150 ($p < 0.05$) (Figure 2).
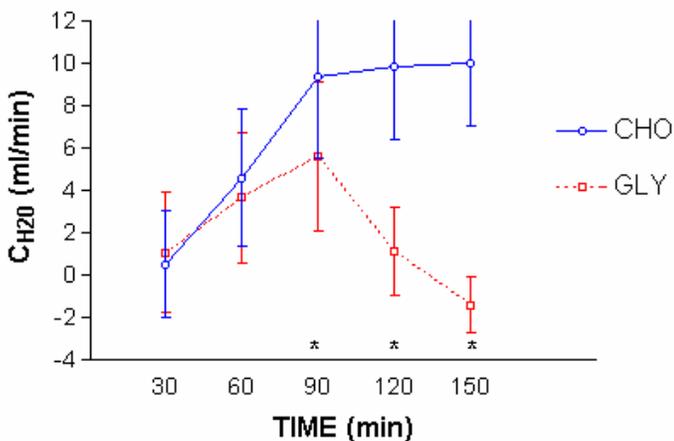

Figure 1. Mean C_{H2O} values for CHO and GLY at rest for 12 subjects. * = significantly different from CHO. C_{H2O}: free water clearance, CHO: 6% carbohydrate/electrolyte drink, GLY: 5% glycerol drink.
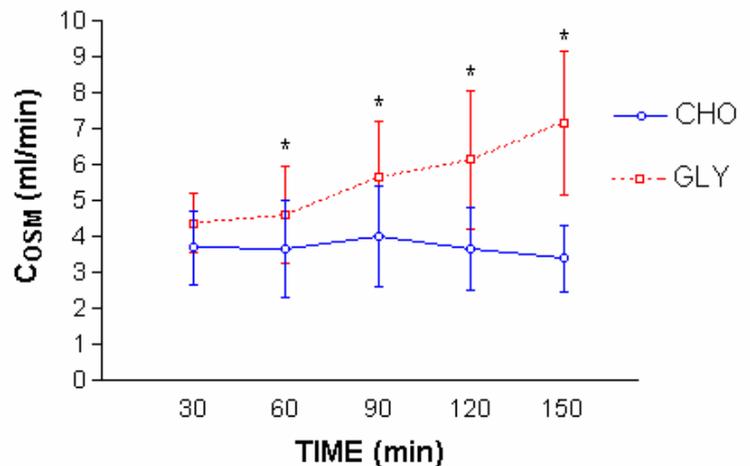
Figure 2. Mean C_{OSM} values for CHO and GLY at rest for 12 subjects. * = significantly different from CHO, C_{OSM}: osmolar clearance.

Glycerol ingestion consistently resulted in higher values of fluid retention (total drink volume – total urine volume) compared to the carbohydrate/electrolyte drink. Specifically, significant differences were found between Trials A (1524 m + CHO) and B (1524 m + GLY), C (CHO + 3659 m) and D (GLY + 3659 m), A and D, as well as B and C (Figure 3) ($p < 0.05$). The change in body mass (ΔBM) was significantly different between Trials A and D, B and C, as well as C and D (Figure 4) ($p < 0.05$).

DISCUSSION

To our knowledge, this is the first study to evaluate the effectiveness of glycerol ingestion on
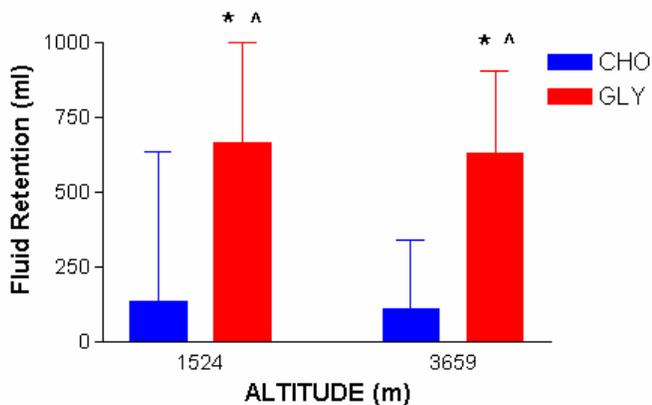
Figure 3. Mean fluid retention values for CHO and GLY at min 150 for 12 subjects. * = significantly different from 1524 m + CHO; ^ = significantly different from 3659 m + CHO. Fluid retention = total drink volume - total urine volume.
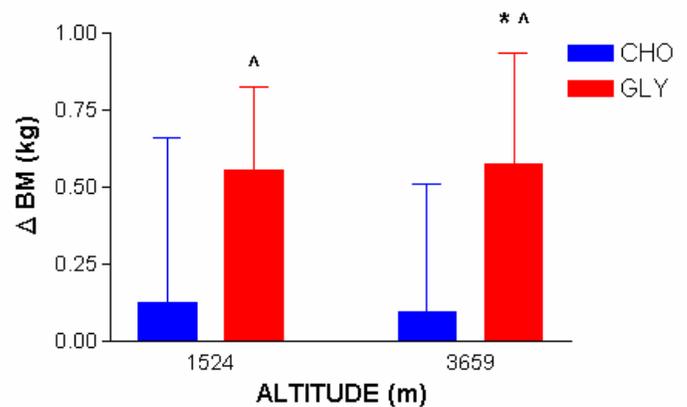

Figure 4. Mean body mass change for CHO and GLY at min 150 for 12 subjects. * = significantly different from 1524 m + CHO; ^ = significantly different from 3659 m + CHO. ΔBM = body mass change in kg.

offsetting the dehydration that is experienced with acute altitude exposure. Glycerol ingestionconsistently resulted in a higher fluid retention with corresponding increases in body mass compared to CHO ingestion. During the 3,659 m trial with CHO ingestion, 7 out of 12 subjects had a reduced BM at 2.5 hr. The increased values for body weight change and fluid retention during GLY suggest that a hyperhydration effect occurred, compared to CHO alone.

We found no significant effects of GLY on ΔPV. Riedesel et al. (21) also found no significant changes in PV (from Hct and Hb) despite a glycerol hyperhydration of 430 ml after 3 hr (increases in plasma osmolality and decreases in urine volume). Both Gleeson et al. (13) and Murray et al. (14) demonstrated improved maintenance of PV during exercise following glycerol ingestion, compared to water or CHO despite the low volume of total fluid ingested in each study (Gleeson = 400 ml; Murray = 647 ml). In the present study, our subjects consumed a mean drink volume of 1,942 ml (range 1,693-2,278 ml), which approximates the amount administered by Lyons et al. (24) (2,045 ml) in a study showing a hyperhydration effect. Glycerol is evenly distributed in all water compartments of the body (15). Plasma is the smallest component of extracellular fluid volume,, amounting to only 7.6% of TBW (25). Thus, if the increased fluid during the GLY trials in our study were equally dispersed throughout the TBW, any augmentations in PV would appear small relative to the larger compartments of TBW (16) and thus fail to contribute to significant cardiovascular changes (26).

The significant differences in C_{OSM} between GLY and CHO suggest that an osmotic gradient occurred with subsequent water reabsorption. Freund (16) reported a 60% retention rate for glycerol and water 3 hours after glycerol ingestion, accompanied by a significant decrease in C_{H2O}. The defining factor in the hyperhydration process is the osmotic action of glycerol (21) and the passive reabsorption of glycerol in the proximal and distal tubules of the kidney. In fact, the reabsorption rate is nearly 100% when the plasma concentration is < 10 mg/dL (16). This mechanism is not observed to the same extent with carbohydrate/electrolyte solutions or water (15) and could potentially benefit the blood volume and PV (16), through enhanced interstitial and intracellular fluid volumes. (24,27). Scheett et al. (26) reported significantly greater PV recovery with glycerol ingestion during rehydration, compared to water alone. They suggested that glycerol may augment the PV, while water may be restricted to the extravascular space.

It is important to note that both endurance training and heat acclimatization can often cause a PV expansion (25). In the present study, subjects had a mean age of 32 yr and VO_2max of 51.85 ml/kg/min, representing a high level of cardiorespiratory fitness. In addition, the majority of data collection for this study took place during the summer months where peak temperature averaged over 90° F. It is possible that our subjects' PV was augmented prior to and throughout the study, thus limiting any further PV expansion through glycerol hyperhydration. Our lack of significant changes in SV could also be attributed to the attainment of an optimal level of PV expansion through training. Increases in exercise SV of 11% following a 400 ml PV and blood expansion (14%) using a dextran solution were reported in untrained men (28). When the protocol was repeated in the trained group, the 400 ml blood volume expansion produced minimal increases in SV. Furthermore, the SV increase in the untrained group was not augmented by additional doses of dextran (28).

Our statistically insignificant differences in HR following glycerol ingestion support findings from previous studies, although Montner et al. (10,29) and Anderson et al. (11) demonstrated significantly lower HR during exercise following glycerol ingestion. Freund et al. (16) increased TBW by ~500 ml following glycerol ingestion without corresponding reduction in HR during rest. Lyons et al. (24) reported a statistically nonsignificant decrease in HR despite reduced urine volumes when glycerol was consumed 2.5 hr prior to exercise in the heat. Murray et al. (14) observed increased PV during exercise following glycerol ingestion, also without a statistically significant attenuated HR response. Latzka et al. (30) had their subjects consume glycerol + water (total volume = 29.1 ml/kg LBM) in a 30 min period. They found similar exercise HR compared to water alone.

We also found no statistically significant differences in cardiac output. Although the CO_2 rebreathing method we used (22) correlates highly with both the direct Fick (r = .94) at rest in normal populations (31), during incremental exercise variability increases, resulting in over-estimations in cardiac output (32). Consequently, the Collier method (18) is suggested for use at rest and during sub-maximal exercise (32). It is also possible that this method lacks the sensitivity to detect small changes in Q, or that a 5% glycerol drink was too dilute to have resulted in significant changes in HR and Q.

Glycerol Contraindications and Safety

Despite the increased chance of headache with glycerol ingestion, and the headache risk of acute altitude exposure (33), we found a 5% mixture to be safe in our group of healthy male athletes. Glycerol ingestion did not result in symptoms of headache or nausea in our three recreational or 9 competitive athletes ranging in age from 21-43 yr. No studies were found on glycerol ingestion in older healthy individuals. Therefore, older athletes and nonathletes may wish to consult their doctor prior to glycerol ingestion. Glycerol hyperhydration has been shown to be well-tolerated in women exercising in both hot (42°C) (24), and moderate (24°C) environments (10).

The increased hyperhydration and glucose levels resulting from glycerol ingestion are contraindicated for individuals with kidney failure, migraine headaches, hypertension, liver disorders, as well as pregnant women (15). Further, glycerol ingestion has been shown to increase serum glycerol in diabetics (34), and therefore, is not recommended for either type 1 or type 2 diabetics. Glycerol ingestion is also not desirable for peritoneal dialysis patients, due to the link between ECFv, inflammation, and mortality (35).

CONCLUSIONS

The major and unique finding of this study was the significantly lower C_{H2O} during glycerol ingestion compared to CHO. This glycerol-induced anti-diuresis is believed to have resulted in the body mass increase and fluid retention at min 150. The results confirm that GLY is superior to CHO in reducing C_{H2O} during hypobaric hypoxia in healthy trained and recreational male athletes.

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