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CONSIDERATIONS FOR REPLACEMENT BEVERAGES:
FLUID-ELECTROLYTE BALANCE AND HEAT ILLNESS

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by Soldiers in the Field

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The case reports of CPT Alitz and Chief Donovan have provided many useful insights for this committee. The purposes of this article are to respond to these case reports and to emphasize the specific need (or lack of need) for carbohydrate-electrolyte solutions, which soldiers experience during duty in hot environments. Because this article will focus on fluids and electrolytes, it is helpful to reiterate the following aspects of their reports: (a) Gatorade was used in dilute form, at 2/3 (Alitz) and 1/4 (Donovan) strength, (b) meals were sacrificed so that the mission could be accomplished, and (c) a rigorous hydration program virtually eliminated heat illness (Donovan) at a time when other U.S. personnel experienced significant casualties. In regard to this third point, Heat Research Division, USARIEM, has received a recent communication describing a similar hydration program at Fort McClellan, AL (1). This program resulted in July-August heat casualties dropping from 21 (1987) to 6 (1988), when troops were placed on a regimen of drinking 0.5 - 1 quart of water per hour.

SALT DEFICITS

If salt and water losses are compared for three continuous foot races--10 km (6.21 mi), 42.1 km (26.2 mi), and 161 km (100 mi)--the total sodium chloride (NaCl) loss on a hot day will be 0.5 - 6 g, 2 - 29 g, and 54 - 93 g. These calculated NaCl losses are based on total sweat losses of 0.5 - 1.5 L, 2 - 6.6 L, and 18 - 35 L (2), respectively, and sweat salt concentrations of 1 - 4 g NaCl/L. If these losses are compared to the daily NaCl intake in garrison dining facilities (95 % confidence limits: 6 - 24 g NaCl/day, ref. 3), or by eating 3 Meals-Ready-to-Eat (MRE) (12.6 g NaCl/day, ref. 4), it is clear that NaCl supplementation may be required in certain physically demanding situations. Although the military relevancy of a 161 km foot race (lasting 17 - 26 h) can be questioned, it is clear that the stress of the triathlon and subsequent deployment, described in CPT Alitz' case study, probably lies somewhere between these 42.1 km and 161 km events.

TABLE 1

Table 1 clarifies this point in more relevant terms. These data (5) describe the effects of a 6-hour simulated desert march on fluid-electrolyte balance. Our measurements (brisk walk, 5 % Incline, 30 minutes exercise per hour, wearing shorts and sneakers) indicated that electrolyte deficits may be encountered (Table 1), when these losses are compared to 24-hour garrison meal intake (95 % confidence limits: 101 - 415 mEq Na⁺/day, 67 - 144 mEq K⁺/day, ref. 3) and MRE intake (216 mEq Na⁺/day, 71 mEq K⁺/day, ref. 4) salt contents. While 6-hour sodium (Na⁺) deficits may be partially reduced via liberal seasoning of meals with table salt, the potassium (K⁺) deficits are less likely to be reduced in this manner.

POTENTIAL OVER-CONSUMPTION OF SALT

In contrast, it is theoretically possible to consume more NaCl than is physiologically required. The calculated 24-hour salt consumption in CPT Alitz' and Chief Donovan's case reports are as follows. Based upon the consumption of 10 L of Gatorade (1.2 g NaCl/L full-strength) per day (Donovan) and 3 MRE per day (12.6 g NaCl, ref. 4), the maximum total salt intakes are calculated as: 8 + 13 = 21 g NaCl (Alitz) and 3 + 13 = 16 g NaCl (Donovan) per day. If one MRE salt packet (4 g NaCl) were consumed at each meal, these values would increase to 33 g (Alitz) and 28 g (Donovan) NaCl/day. COL Schnakenberg noted earlier that soldiers eat approximately 70% of all MRE contents in a temperate environment (6) and that few soldiers (< 4%) use the MRE salt packets, therefore a realistic estimate of these NaCl intakes then becomes 8 + 9 = 17 g (Alitz) and 3 + 9 = 12 g (Donovan) NaCl per 24 hours. Dr. Buskirk has noted that 7 g NaCl/day was historically recommended for heat acclimatized soldiers. This agrees well with Conn's 1949 research (7), which demonstrated that heat acclimatized males adapted to diets containing 6 g NaCl/day (from 12 g NaCl/day) after 5 - 15 days of this diet. It is likely, then, that the military units described in these case reports were consuming more NaCl each day than they required. Dr. Knochel

has noted that the human kidney will readily remove such levels of excess salt, as they are consumed. His point is accurate and well taken, yet the need for salt supplementation is greater during the initial 3 - 5 days of heat exposure because the kidneys require 3 - 5 days (and the sweat glands require 5 - 10 days) of heat exposure to maximally conserve Na^+ (8). Symptoms and casualties of heat syncope and heat exhaustion are greatest during this period, and decrease notably after the fifth day (9). This can best be explained by the fact that the primary adaptations during the initial 3 - 5 days of heat acclimatization are cardiovascular, and emphasizes the need for adequate salt intake, to maintain extracellular fluid and plasma volumes. Dr. Nadel's presentation, which demonstrated that plasma volume is maintained during exercise in the heat more effectively by a saline solution (versus water), further supports this concept.

The only study which has examined extremely high salt consumption during heat acclimatization is the one by Dasler et al., published as an abstract in 1973 (10). These researchers found that subjects exhibited impaired heat acclimatization responses, when eating high levels of salt (22.5 - 30 g NaCl/day). These responses included cardiovascular impairment, decreased optimal work capacity, as well as increased excretion of K^+ , bicarbonate, and other anions. This impaired heat acclimatization response may have been due to inadequate water intake by Dasler's subjects, because the water requirement increases approximately 1 L for each 5 g NaCl added to the diet (11). In addition, Knochel and Vertel (12) have implicated salt loading as a possible factor in the production of potassium deficiency, rhabdomyolysis, and heat injury. These two reports impact on the evaluation of carbohydrate-electrolyte replacement beverages, because a soldier could theoretically exceed the NaCl intake in Dasler's study if he ate three MRE (13 g NaCl/day), ate three MRE salt packets (12 g NaCl/day), and drank 10 L of Gatorade

(12 g NaCl/day full-strength) in a 24-hour period. In CPT Alitz' and Chief Donovan's units, these theoretical NaCl totals would be 33 g and 28 g.

CASE REPORT A: TEN HEATSTROKE PATIENTS

During the past two years, we have evaluated the time course and extent of recovery in prior heatstroke patients. Ten active duty male soldiers have come to our laboratory for 14-day investigations of their thermoregulatory and heat acclimatization abilities, as well as evaluations of blood chemistry values and fluid-electrolyte balance. This work will be published elsewhere, but it is useful for us to consider the events of the day on which these men experienced heatstroke. Nearly all of these soldiers experienced heatstroke (verified by rectal temperature $> 104^{\circ}\text{F}$, elevated serum enzymes, altered mental status) at Fort Benning, GA, which presents a hot, humid environment at mid-day. In most cases, they were running in formation at 7.0 - 8.5 min per mile pace. However, 8 out of 10 of these men collapsed prior to 0730h, when the ambient dry bulb temperature was $69 - 79^{\circ}\text{F}$ or lower—certainly not the environmental conditions which one would expect to induce heatstroke.

Prior to the initiation of testing, each volunteer was interviewed in regard to factors which may have predisposed him to heatstroke. Based on daily physical training and environmental conditions, we defined 5 of these men heat acclimatized and 5 non-acclimatized. The climate of their residence (for four years prior to the heatstroke) varied from very hot to temperate. Table 2 further defines the predisposing factors which these soldiers reported. Four factors were verified by at least 50 % of these volunteers: sleep deprivation, fatigue, lengthy heat exposure, and a long exercise bout or workout within the five days prior to heatstroke. Although no information was gathered on eating consistency, carbohydrate-electrolyte replacement drinks evidently would not have assisted these ten heatstroke patients, who had access to garrison meals during training, unless they chose to eat only a

TABLE 2

portion of the meals offered to them. This occurs in some field situations (6), but the survey of basic trainee eating habits by Rose et al. (3), indicated that males left on their plates only 2 - 3 % of the daily Na⁺ offered in their three garrison meals; while females did not eat 7 - 10 % of the daily Na⁺ offered in their three garrison meals. The issue of anorexia, upon arrival in a hot environment, is unresolved.

CASE REPORT B: HEAT EXHAUSTION IN PANAMA

A scenario, similar to the one which Chief Donovan described, occurred in Panama during 1985. Eleven heat exhaustion cases occurred during one field training exercise (FTX) at the Gatun drop zone. The ambient temperature and humidity, which are very stable year-round in Panama, evidently had not changed prior to this FTX, but the events which occurred during the 36 hours prior to this incident were crucial. This FTX occurred on a clear, sunny day ($T_{db} > 80^{\circ}F$). The troops were wearing full combat gear, including rucksack, weapon, parachute and reserve chute. Most were heat acclimatized, and most had been trained to drink and sprinkle water on their bodies. This paratrooper unit had spent 24 - 36 hours prior to the FTX packing gear, organizing, and planning the next day's activities; this led to sleep deprivation. Although these soldiers carried 1 quart and 2 quart canteens, their busy schedule may have resulted in inadequate water and meal intake. Heat exhaustion is usually a fluid depletion problem which is aggravated by exercise in the heat, resulting in circulatory collapse. It appears that a lengthy period of fluid imbalance, coupled with a 2-hour wait on the runway in non-air conditioned aircraft, precipitated these eleven cases of heat exhaustion. Dense foliage (8 - 10 feet tall, thick, little or no air movement) at the drop zone was the final contributing factor. As soldiers landed, they were required to move to a pick-up point through this dense foliage. It is likely that a carbohydrate-electrolyte replacement fluid, available during the 36-hour preparation period, would have helped these soldiers maintain

performance throughout the FTX, and may have helped them avoid heat exhaustion (9,13).

CASE REPORT C: HEAT EXHAUSTION AMONG RESERVISTS IN TEXAS

Members of the Fifth Army Reserve conducted their annual two-week field training exercise (FTX) at Fort Hood, TX, in June 1988. Our research team evaluated heat exhaustion patients who were sent to the 44th Evacuation Hospital. Blood chemistry, hematological and total body water measurements were made on four heat exhaustion patients, 3 males and 1 female. Table 3 describes the total body water values (deuterium oxide, D₂O) for these four patients, as well two control subjects. The percentage of body weight which total body water (TBW) represents in normal males has been reported as $55.6 \pm 5.0\%$, in 25 measurements on 11 subjects (14). This agrees well with the values for normal subjects presented in Table 3, (58 and 57 %), but not for the four heat exhaustion patients, who had ratios of total body water-to-body weight of 70, 93, 83 and 86 %. A plausible hypothesis involves disrupted fluid adsorption at the intestine, leading to impaired/delayed D₂O equilibration with total body water. Our experiments indicate that plasma D₂O equilibration occurs in 2 - 3 hours, in normal subjects. We believe that minimal D₂O entered the body water space through the intestine, the total body water pool appeared to be larger than it actually was (Table 3), and TBW was thereby overestimated. The involvement of impaired intestinal absorption in heat exhaustion (13) and other illness (15) has been described elsewhere. These results, similar to malnutrition cases (16), may mean that a carbohydrate-electrolyte solution will optimize intestinal water absorption.

SCENARIO-SPECIFIC NEEDS

Recent review articles (17,18) have emphasized the fact that the efficacy of consumption of carbohydrate-electrolyte solutions depends on the research

TABLE 3

protocol employed. There are two situations in which carbohydrate-electrolyte beverages clearly appear to maintain performance: (a) when a deficiency exists in either carbohydrate or electrolyte stores, and (b) when prolonged, continuous exercise of at least 60 minutes duration (17) is performed.

Dr. Coyle has described the importance of timing as a factor determining the efficacy of carbohydrate consumption. Lamb and Brodowicz (18) similarly have published a review paper which noted that: (a) carbohydrate consumption 0 - 15 min before exercise may positively effect endurance performance, and (b) there is no published report of a positive effect of carbohydrate intake on performance, when carbohydrate was fed 15 - 60 minutes before exercise. This is probably due to a reduced blood glucose level, following a rapid rise in insulin concentration.

Although many stressful military scenarios suggest that carbohydrate-electrolyte supplements would improve performance (i.e. missed meals, lack of heat acclimatization, diarrheal disease, and exercise in impermeable protective clothing), some scenarios contra-indicate the consumption of carbohydrate-electrolyte supplements. For example, total dissolved solids may reach 1.0 g/L in fresh water, 1 - 20 g/L in brackish water, and > 35 g/L in saline water (19). NaCl constitutes 85 % of these total dissolved solids by weight. For soldiers drinking 10 - 18 L of fresh water per day (see above), this amounts to 9 - 15 g of NaCl added to an individual's total solute load. This amount of NaCl would be much larger if brackish or saline water were consumed.

The task performed by soldiers also should be considered in determining whether carbohydrate-electrolyte fluids are necessary to maintain performance. Table 4 presents the Military Occupational Specialty (MOS) Classifications of the U.S. Army, as published by Sharp et al. (20) in 1980. The reader will note that these classifications have been categorized by fitness requirements (high, medium, or low) for strength and stamina. It is instructive to note that 47 % of all enlisted personnel work in MOS

TABLE 4

categories which require medium-to-low strength and stamina. Thus, it appears that they seldom are placed in situations which require carbohydrate-electrolyte supplementation. Their normal dietary intake (e.g. garrison meals or MRE) ought to replace all metabolized carbohydrates and lost electrolytes.

SUMMARY

The above facts have been presented to support the concept that carbohydrate-electrolyte replacement fluids may be necessary in some, but not all, military field situations. The greatest need for carbohydrate-electrolyte replacement fluids will be experienced by soldiers who (a) lose more than 8 L of sweat per day; (b) are not heat acclimatized (e.g. during the initial 8 days of field living); (c) are performing a prolonged, continuous exercise bout (> 60 min); (d) skip meals, have meals interrupted, or encounter anorexia due to a hot environment; (e) experience a caloric deficit > 1000 Kcal/day; or (f) are ill with diarrheal disease. The fluid-electrolyte needs of soldiers will be specific to the intensity, frequency and duration of the exercise involved, as well as the environmental stress encountered. This information is not presented to imply that many different solutions are required, but rather that the best use of such fluids will be recognized with proper soldier training (i.e. when to use them) and simple instructions for field implementation. It appears that carbohydrate-electrolyte replacement fluids, like a weapon, should be available to the soldier, for use when needed.

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EXPERIMENTAL DESIGN

- 12 healthy males
- 40.6°C db, 25.5°C wb
- treadmill walking at 1.34 m/s, 5 % grade
- ad libitum water intake

FLUID-ELECTROLYTE LOSS PER 6 HOURS

- sweat loss: 3.5 ± 0.1 L
- sweat Na⁺ concentration: 12.7 - 46.7 mEq/L
- sweat K⁺ concentration: 1.7 - 4.8 mEq/L
- Na⁺ loss: 72 - 244 total mEq*
- K⁺ loss: 23 - 70 total mEq*

PROJECTED ELECTROLYTE LOSS PER 24 HOURS**

- Na⁺ loss: 193 - 425 mEq/L
- K⁺ loss: 62 - 240 mEq/L

* - urine + sweat (measured via whole-body washdown)

** - based on 8 L sweat loss and constant urinary electrolyte loss, per 24 hours

| <u>PREDISPOSING FACTORS</u> * | <u>NUMBER OF SUBJECTS REPORTING</u> ** |
|---------------------------------------|--|
| sleep deprivation | 7 |
| fatigue | 6 |
| long exercise bout(s) | 5 |
| long heat exposure | 5 |
| heat wave | 4 |
| reduced sweat secretion | 3 |
| concurrent fever or disease | 3 |
| excessive use of alcohol | 1 |
| excessive use of tobacco | 1 |
| eating a low salt diet | 1 |
| recent visit to doctor | 1 |
| taking medication for other complaint | 1 |
| dehydration | 1 |

* - during the 5 days prior to heatstroke

** - out of ten subjects

TOTAL BODY WATER (D₂O) COMPARISON

| <u>SUBJ</u> | <u>SEX</u> | <u>AGE</u> (yr) | <u>Wt</u> (kg) | <u>HT</u> (cm) | <u>TBW</u> (L) | <u>TBW:M</u> (%) | <u>URINE</u> <u>SP.GR.</u> |
|---|------------|--------------------|-------------------|-------------------|-------------------|---------------------|-------------------------------|
| NORMAL SUBJECTS | | | | | | | |
| A | m | 29 | 102.5 | 183 | 60 | 58 | 1.024 |
| B | f | 28 | 52.8 | 154 | 30 | 57 | 1.006 |
| HEAT EXHAUSTION PATIENTS - FORT HOOD, TX - JUNE 1988 | | | | | | | |
| A | m | 45 | 115.7 | 193 | 81 | 70 | 1.025 |
| B | m | 28 | 107.5 | 180 | 99 | 93 | 1.005 |
| C | f | 24 | 49.4 | 157 | 41 | 83 | 1.024 |
| D | m | 25 | 72.6 | 183 | 62 | 86 | 1.002 |

M.O.S. CLUSTERS

| <u>FITNESS REQUIREMENTS</u> | <u>BRANCH</u> | <u>TOTAL MOS's</u> | <u>% ENLISTED</u> |
|-----------------------------|-------------------------------------|--------------------|-------------------|
| <u>STRENGTH STAMINA</u> | | | <u>PERSONNEL</u> |
| HIGH HIGH | ENGINEER, FIELD ARTILLERY, INFANTRY | 10 | 19 |
| HIGH MEDIUM | ARTILLERY, FIELD ARTILLERY, MEDICAL | 39 | 13 |
| HIGH LOW | ENGINEER, MUNITIONS, TRANSPORTATION | 63 | 21 |
| MEDIUM LOW | INTELLIGENCE, SIGNAL, ENGINEER, QM | 53 | 21 |
| LOW LOW | ADMIN, ENGINEER, INTELL., TRANS. | 184 | 26 |

Table 4

- SHARP et al., USARIEM, 1980