

Sports Hydration: '07

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Two Page Executive Summary

For the past 40 years, endurance athletes have been told to “*drink as much fluid as you can tolerate*” during their sporting event. Since the late 1960’s, research, discussion and sports hydration have focused solely on the prevention of dehydration and its medical consequences. The deaths of several mostly female marathon athletes and the hospitalization of many others from cerebral edema due to excessive fluid consumption caused sports physicians to recommend reducing the fluids consumed from 1000-1200 ml per hour to 400-800 ml per hour. We discuss cerebral edema, dehydration, fluid recommendations, sports drink formulations and finish with suggestions for fluid, sodium and carbohydrate consumption during endurance events.

Research has shown that depending on the temperature, humidity and overall conditioning, athletes engaged in vigorous exercise can lose 1500-3500 ml of sweat and 1300-5000 mg of sodium per hour. Several studies have also demonstrated that on average, women lose much less fluid through sweat than men, an average of 450-570 ml per hour compared to 780-1120 ml per hour for men. This is important because it appears that most cases of cerebral edema have been women running a 5 hour + marathon, who are drinking more liquids than they are sweating out.

The kidneys control the retention and excretion of water and sodium in order to keep the body in a state of fluid balance, indicated by the overall combined levels of dissolved salts, sugar and other solids called **the osmolality**. **A normal osmolality is 282-295 mOsm/kg**. When sweat causes **dehydration**, the plasma sodium and osmolality increases, causing the antidiuretic hormone vasopressin to be released, resulting in the kidneys excreting sodium and retaining water. This process continues until the high osmolality is reduced to normal. The athlete also gets very thirsty, because drinking water also lowers the plasma osmolality.

Normally, when an athlete (or anyone) drinks too much water or sports drink, little vasopressin is released and the kidneys retain salt and excrete water producing large volumes of dilute urine. This response continues until the low osmolality increases and becomes normal again.

Sometimes, drinking more fluids than you excrete by sweating or urination can cause the body to retain them and little urine is produced. Because sodium levels in sports drinks are only 1/5 that of blood and water has no sodium, these absorbed fluids lower the plasma sodium (**hyponatremia**) then diffuse from the blood to the brain in an attempt to balance out the lower sodium in the blood. The result is increased pressure in the head which slows blood flow and oxygen to the brain, resulting in **cerebral edema** and death. This “**water intoxication**” also can occur with Ecstasy use and hazing events with forced water drinking. This inappropriate release of vasopressin in spite of a low osmolality and low plasma sodium is called **SIADH (Syndrome of Inappropriate ADH Secretion)**.

Deadly Heat:

The weather conditions (temperature, humidity, sunlight, and wind) during an athletic event directly influence the intensity and the success of the event as well as the health and safety of the participants. Non-conditioned athletes, and participants who are obese, taking certain drugs or have any of a variety of medical conditions can easily become dehydrated and suffer heat stroke in which the body’s temperature quickly rises causing organ failure and death. This can occur even during a 10k run! Because 75% of heat loss occurs through evaporative cooling, understanding heat effects and proper hydration is critical for survival in the armed forces.

Elevated temperature and humidity are especially harmful and can be deadly to children and adolescents who have less body surface for evaporation, a reduced sweat response, less total body water and a reduced capacity to dissipate heat.

Symptoms of Hyperthermia are similar to SIADH. A mistake in diagnosis can mean permanent brain damage or death. Both can be present, but with SIADH, the body is already swollen with excess fluids. Additional fluids can kill! Rapid determination of plasma sodium aids in proper diagnosis and can save lives.

Hyperthermia/Heat Stroke or SIADH?

- **SIADH:** Vomiting, then disorientation, drowsy confused agitated behavior, followed by seizures, coma, brain damage and death from cerebral edema.
- **Heat Cramps:** are muscle spasms, especially in the stomach or legs after intense physical activity, and are typically related to a loss of sodium through intense sweating. Athletes with the highest sweat sodium losses tend to experience heat cramps much more than athletes with lower sodium sweat losses. Additional sodium supplementation may be needed.
- **Heat Exhaustion:** Symptoms include dizziness, weakness, thirst, uncoordination, stomach/muscle cramping (from lack of salt), nausea and sweating, cold/clammy skin, and normal body temperature.
- **Heat Stroke:** Symptoms include confusion, combativeness, bizarre behavior, dizziness/fainting, staggering (like stupor), absence of sweating, strong/rapid pulse, delirium, coma, brain damage from 104° and higher body temperatures, and death.

Marathon Results

Now that marathon guidelines call for drinking only 400-800 ml of fluid an hour, instead of 1000 ml +, fewer athletes are getting water intoxicated. We now have a mix of both dehydrated athletes as well as some with lower sodium.

For the fastest absorption of sports drinks (or any liquid) during athletic events, its total concentration of salt and sugars (osmolality) should be lower than the plasma osmolality (less than 280 mOsm/kg). Our experiments indicate that the two most popular sports drinks; Gatorade and Powerade have elevated osmolalities and as such will have delays in gastric emptying and absorption.

- **Gatorade:** Average 374 mOsm/kg, Range (346-402 mOsm/kg)
- **Powerade:** Average 417 mOsm/kg, Range (409-427 mOsm/kg)

This elevated osmolality may be why athletes complain of stomach cramping when they drink only sports drinks. Because of gastric problems, many athletes alternate between sports drinks and water and as such get less carbohydrates and sodium than they may need to perform at their best. Cytomax, a sports drink with an average osmolality of 164 mOsm/kg and an osmolality range of 156-172 mOsm/kg may be a good alternative.

In addition to fluids, athletes also need carbohydrates during the race to maintain energy and performance and some sodium to help in water retention and reduce low plasma sodium (hyponatremia). To ingest the **recommended 30-60 gm of carbohydrates** some athletes every hour are eating one ounce of Fig Newton's (two of them) which have 22 gm of carbohydrates and 12 gm of sugar, or one ounce of Sports Beans which have 25 gm of carbohydrate and 19 gm of sugar.

The large amount of sodium lost during the race should be replaced in the 24 hours after the race. Besides eating salty meals, tomato juice is a good choice. At 2800 mg/L it has almost three times the sodium of Pedialyte and one liter also contains 1790 mg of potassium, 42 grams of carbohydrate and 29 gm of sugar!

In Conclusion; To maintain peak performance, while avoiding both dehydration and cerebral edema, endurance athletes must educate themselves regarding hydration choices during and after the event. They should be keenly aware of their own physiology, and monitor fluid consumption more closely, as well as their thirst and body weight during the event. Although it appears that drinking 400-800 ml of fluid per hour will decrease the incidence of cerebral edema, fluid consumption must be balanced with individual needs. What also seems apparent is the need for point of care testing of serum sodium. An accurate sodium level is critical for both appropriate diagnosis and treatment of sickened athletes. Without a serum sodium level, it is too easy to misdiagnose cerebral edema as dehydration, in which case the resulting treatment could kill the athlete.

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Overview

For the past 40 years, endurance athletes have been told to “*drink as much fluid as you can tolerate*” during their sporting event. The death of a healthy woman during the 2002 Boston Marathon and the hospitalization of several others, all from cerebral edema, prompted a reexamination of this doctrine. We discuss the physiology of sodium and water loss during endurance sporting activities, dehydration, heat stroke, the Syndrome of Inappropriate ADH secretion (SIADH) and cerebral edema. We then discuss “sports hydration” including the new fluid recommendation guidelines. Osmolality and the physiology of rehydration is discussed and related to our osmolality experiments with both infant rehydration solutions and sports drinks. We finish with a discussion of the ingredients and formulations of the current popular sports drinks and recommend changes to improve their functionality. By gaining a better understanding of fluid and electrolyte loss and replacement, the endurance athlete should be able to make better rehydration choices, thereby maintaining performance while minimizing the risk of both dehydration and cerebral edema.

Water Balance

- **The body tightly controls water and sodium excretion and retention in order to maintain a plasma osmolality of 282-295 mOsm/kg and allow cellular functions to take place.**
- Increases in plasma osmolality usually from water loss (urine/sweat) cause ADH (arginine vasopressin) to be released from the pituitary gland.
- Vasopressin acts on the renal collecting tubule activating adenyl cyclase, stimulating protein kinases, and resulting in water reabsorption from the lumen of the nephron back into the circulation, producing concentrated urine and a lowered plasma osmolality.
- The thirst mechanism is also activated by an increased osmolality resulting in the need to consume fluids.
- **With NO ADH present, the kidney will produce a large volume of dilute (low osmolality) urine.**
- **With increasing amounts of ADH, the kidney will produce smaller and smaller volumes of concentrated urine. Sodium will be excreted while water is retained.**

Diabetes Insipidus

- **Polyuria:** The production of large volumes of dilute urine, a condition associated with Diabetes Insipidus.
- There are several forms but mainly a lack of vasopressin results in the loss of osmotic regulation and the inability to concentrate the urine.
- Patients drink excessive amounts of fluid (*polydipsia*) in response to thirst from excessive production of dilute urine.
- With Diabetes Insipidus, even after fluid restriction the urine osmolality is less than 300 mOsm/kg.
- With primary Polydipsia, a neurotic condition of excessive water consumption, after fluid restriction, the urine osmolality is greater than 750 mOsm/kg.
- Desmopressin, a synthetic analog of Arginine Vasopressin, is used to treat Diabetes Insipidus.

Ecstasy Use and SIADH

- **SIADH: Syndrome of Inappropriate Antidiuretic Hormone Secretion**
- Excessive sweating and physical exertion leads to dehydration and vasopressin release. Excessive fluid consumption and continued sodium excretion with continued vasopressin release results in fluid retention even though plasma sodium and osmolality are low. The mechanism for this response is not understood.
- Vomiting follows, then disorientation, drowsy confused agitated behavior, followed by seizures, coma, brain damage and death from cerebral edema.
- How much water is too much? Depending on body weight, as little as a gallon of water ingested over a short time can dilute and significantly lower the plasma sodium causing cerebral edema and possibly death. Most cases of Ecstasy use/water Intoxication have been young women. Because of their lower body weight, their plasma and extracellular fluid volumes are lower than men, see page 7.

Hyponatremic States Following MDMA Ingestion ^[1]

- In the two fatal MDMA ingestions, cerebral edema developed within 5 hrs of the ecstasy ingestion. In the 14 survivors below:
 - Admission serum sodium averaged 119 meq/L with a range of 107-128 meq/L
 - Admission serum osmolality averaged 250 mOsm/kg with a range of 236-267 mOsm/kg
 - Admission urine osmolality averaged 535 mOsm/kg with a range of 355-733 mOsm/kg

Ecstasy Use and the Serotonin Syndrome

- Hyper stimulation of serotonin receptors from massive serotonin release leads to hyperthermia, impaired mental status and muscle rigidity.
- High physical activity, high ambient temperature, and inadequate fluid consumption contribute to the hyperthermia, dehydration and muscle damage.
- This impaired physical condition can potentiate MDMA's action on the thermoregulatory center leading to rhabdomyolysis. Its resulting muscle breakdown clogs the nephrons and results in kidney failure in days to one week.
- Relationship of Serotonin Syndrome, thirst response and SIADH?

History: Athletics, Dehydration and Sports Drinks

- From Roman times to the late 1960's athletes abstained from fluids during races. Tough athletes did not need fluids and the water weight would "*slow them down*".
- That advice changed in 1969 to ***drink as much as possible*** after articles appeared on the dangers of dehydration. In 1969, Gatorade also became the official sports drink of the NFL.
- Gatorade was developed in 1965 by a team of four Florida University Doctors and a Florida Gators football coach. Introduced to the team in the mid 1966 season, it is credited with their winning seasons beginning in 1967. The Kansas City Chiefs were the first NFL team to use it starting in 1967. It is credited with reversing their losing season and winning Super Bowl four.
- The Gatorade Sport Science Institute (GSSI) founded in 1988, operates as a "*research and educational facility dedicated to enhancing the performance and well being of athletes*".
- Gatorade's research and efforts over the past 40 years are largely responsible for dramatically reducing athletic dehydration and its medical consequences. "*If you want to win, you've got to replace what you lose*" is one of their advertising themes.
- After a death from over hydration and Cerebral Edema in the 2002 Boston Marathon, the ***drink as much fluid as possible*** advice was changed to ***drink only 400-800 ml/hr.***

We are now at a crossroads of sports hydration!

The purpose of this report is to provide an unbiased look at sports hydration and review the present and future trends in the research and marketing of sports hydration beverages. Since 1969, the focus has solely been at preventing dehydration and its consequences. With the realization that too much fluid consumption in certain individuals can lead to fluid retention, cerebral edema and death, physicians and athletic trainers are revisiting the recommended fluid consumption guidelines. Much of the following information has been obtained from publications and material before 2003 that only focused on the prevention of dehydration. The updated fluid recommendations based on the **Position Statement from the International Marathon Medical Directors Association in July 2006** is then discussed. This represents a paradigm shift in sports fluid hydration.

Effects of Dehydration: ^[2]

- Increase in core temperature: 0.15-0.20° C for every 1% loss in weight due to sweating. This is a thermoregulatory effect related to decrease in available water for sweat production.
- Cardiovascular strain: decreased stroke volume, increased heart rate, increased vascular resistance and possible lower cardiac output, all proportional to the water loss.
- Decrease in blood muscle perfusion can elevate lactate levels and decrease performance.
- Decrease in physical work capacity of 35-48% for extended exercise with 2.5% loss in water weight.

Sports Dehydration Studies

The following studies illustrate the surprising large water and sodium losses which occur during non-marathon sporting events.

- Soccer players were tested before and after a 90 minute training session. The temperature averaged 80^o, and the humidity averaged 55%. The sweat loss ranged from 1620-2446 ml (average 2033 ml). The sodium loss ranged from 1725-2830 mg (average 2280 mg). ^[3]
- 17 tennis players had their fluid and sodium losses measured after long tennis matches in hot conditions and 55% humidity. Average sweat loss was 2600 ml/hour and the average sodium loss was 2715 mg/hour. More troubling was the range of the losses. Sweat losses ranged from 2000-3400 ml/hour and sodium losses ranged from 1375-4770 mg/hour. These losses are severe given that a tennis match can last up to 4 hours. The authors advise drinking up to 2 liters per hour during the match to minimize the fluid and sodium deficit and consuming 6 liters after each match, but note that these volumes may be impractical. ^[4]
- NCAA football players were tested during double sessions for sweat and sodium losses. Players that experienced heat cramping had an average sweat sodium loss during each 2.5 hr session of 5100 mg (2800-7400 mg). Players that did not report heat cramping experienced sodium losses averaging 2200 mg (500-3900 mg). Sweat loss was similar between the two groups averaging 4000 ml (2900-5100 ml) for the players with heat cramps and 3500 ml (1900-5100) for players without heat cramps. ^[5]
- Cyclists preparing for a 108 km road rally took a 90 minute spinning class. The 14 men participating had an average sweat loss of 1120 ml/hr, whereas the 12 women had an average sweat loss of 570 ml/hr. ***These large gender differences may offer a partial explanation to the disproportionate female cases of hyponatremia seen in marathon runs (discussed later in the report).*** ^[6]
- Cyclists performing a 30 minute workout at 40% VO₂ max had their sweat losses measured. Male sweat losses averaged 780 ml/hr [487-1073] whereas females averaged 450 ml/hr [365-535]. The differences were attributed to differences in gender skin surface area. ^[7]

From The Mayo Clinics™ Website ^[8]

“As little as a two to three percent decrease in body water has been found to negatively affect performance and cardiovascular function”

“Thirst is not a good early warning sign for dehydration. By the time your child is thirsty, they may already be dehydrated”

Dehydration Symptoms

- Feeling dizzy or lightheaded
- Having a dry or sticky mouth
- Producing less urine or a dark yellow urine instead of a clear or light yellow urine

Preventing Dehydration - American Academy of Pediatrics (AAP) ^[9]

The American Academy of Pediatrics is very concerned about dehydration and its effects on student athletes and has published guidelines related to outdoor exercise, including the heat index and the recommended amount of fluid replacement. **Elevated temperature and humidity are especially harmful and can be deadly to children and adolescents who have less body surface for evaporation, a reduced sweat response, less total body water and a reduced capacity to dissipate heat.** (Note fluid volume table on pg 7).

Heat Index

- < 75 all activities allowed
- 75-78 rest periods in shade, drink fluids every 15 min
- 79-84 children who have not acclimated or at risk should stop playing
- 85 cancel all outdoor activities

Hot/Humid Conditions

- Reduce activities lasting over 15 min
- Make children drink 5 oz water or sports drink every 15-20 min
- Make adolescents drink 8 oz water or sports drink every 15-20 min

Heat Index Chart																
% Relative Humidity																
	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Temperature	110	108	112	117	123	130										
105	102	105	108	113	117	122	130									
100	97	98	102	104	107	110	115	120	126	132						
95	91	93	95	96	98	100	104	106	109	113	119	124	130			
90	86	87	88	90	91	92	95	97	98	100	103	106	110	114	117	121
85	81	82	83	84	85	86	87	88	89	90	92	94	96	97	100	102
80	76	77	78	78	79	79	80	81	82	83	84	85	86	87	88	89

Legend	
80-89 degrees	Fatigue is possible with prolonged exposure and/or physical activity.
90-104 degrees	Sunstroke, heat cramps and heat exhaustion are possible with prolonged exposure and/or physical activity.
105-129 degrees	Sunstroke, heat cramps and heat exhaustion are likely. Heat stroke is possible with prolonged exposure and/or physical activity.
130+ degrees	Heatstroke/sunstroke is highly likely with continued exposure.

Heat Index Chart courtesy of Anthony Watts, Meteorologist

Deadly Heat and Exertional Heat Illness

The weather conditions (temperature, humidity, sunlight, and wind) during an athletic event directly influence the intensity and the success of the event as well as the health and safety of the participants.

The heat index provides a rapid and helpful estimate of heat stress and possible health dangers but its use is limited because it uses just humidity and temperature in its calculation. In many situations, however, the heat index may be all the athletes have to go on. Note that direct sunlight which occurs during the most intense hours of the day, 11 am to 3 pm, can add up to 15 points to the index!

Running an endurance race under hot, humid and sunny conditions can be a challenge. At 90° and 70% humidity, the heat index is 106°. The heat index chart classifies this situation as orange meaning that sunstroke, heat cramps and heat exhaustion are likely and heat stroke is possible with continued activity. As a reference, the American Academy of Pediatrics recommends canceling any outdoor activity when the heat index is over 85! Under elevated heat indices the athlete's loss of both water and sodium can be extreme. Sodium loss will be especially high in non-conditioned athletes.

WBGT ^[10]

The WBGT (Wet Bulb Globe Temperature) introduced in 1957 for Marine Corps training, takes into account the effects from direct sunlight and wind in addition to temperature and humidity and thereby factors in the cooling effects from evaporation. Although the military and now the WHO (World Health Organization) have sanctioned WBGT, it is only occasionally used. We feel that all athletes could benefit by understanding and urging the use of WBGT to gauge heat stress. Three thermometers are used to calculate WBGT:

- **Dry Bulb Temperature (DBT)** The ambient temperature measured by a standard thermometer placed in the shade.
- **Black Globe Temperature (GT)** The temperature measured by a thermometer with its bulb inserted into a 6 inch diameter black ball placed in the sun. This corresponds to radiant heat.
- **Wet Bulb Temperature (WBT)** The temperature measured by a thermometer that has its bulb wrapped in a cotton sleeve, resting in distilled water so that it always remains wet. The humidity, temperature, sun and wind influence evaporation and evaporative cooling which lowers the temperature. With low humidity this temperature may be several degrees less than the DBT. With high humidity the two temperatures will be similar indicating a reduction in evaporative cooling. Evaporative cooling is the body's main mechanism for dissipating heat so this temperature is similar to the effect of sweating and evaporation from the skin.

$$\text{WBGT} = 0.1\text{DBT} + 0.2 \text{GT} + 0.7 \text{WBT}$$

We can see by the factors applied to each measurement that 70% of the total WBGT is due to the influence of evaporative cooling. ***As the humidity approaches 100%, no evaporative cooling will take place and in effect, the body will begin to severely overheat. Direct sunlight will worsen the effect.***

Activity risk using WBGT measurements

- **Low Risk Below 65° F**
- **Moderate Risk 65-73° F**
- **High Risk 73-82° F:** Heat sensitive individuals (Obese, Poor Fitness, Unacclimatized, Dehydrated, Head Injury) should not compete
- **Very High Risk above 82° F:** Postpone Race

Unfortunately, the logistics of actually using WBGT in a race can be difficult to impossible. When the sun is just coming up, the influence of the GT measurement is minimal because the black bulb will not be absorbing heat. The high humidity during the night will normally decrease somewhat early on as the temperature increases. These changing conditions will dramatically affect the WBGT as the race progresses, so in order to be of use there must be a notification system throughout the race course. The Marine Corps system uses posted flags across Paris Island. WBGT of 90° F is Black Flag, 88-89.9° is Red Flag, 85-87.9° is Yellow flag, and 75-84.9° is green flag. I would think that with appropriate communication, a color flag system could be used in a marathon, thereby reducing heat illnesses and the occurrence of heat stroke.

Heat Conditioning ^[11]

Well conditioned athletes have an increased plasma volume, enhanced cardiac capability, more rapid and greater sweat production along with less sodium in their sweat. This gives these athletes a distinct advantage when participating in intense or long athletic events under hot conditions. They also have fewer and less severe medical consequences from the heat. Training under hot conditions for 10-14 days prior to the event improves sweat loss, and reduces heart rate and core temperature, thereby improving performance and reducing health consequences from the heat. Heat conditioned athletes have average core temperatures 1-1.5° below those of non-conditioned participants at like times in the race. One degree can mean the difference between heat stress and heat stroke!

10K Fun Runs are especially troubling. Most people believe marathon participation requires intensive training over several months. In fact the rigorous qualifying times for the Boston Marathon may be one reason why there are so few serious medical problems during that race. However, almost all marathons and all 10K events do not require a qualifying time, therefore anyone; regardless of ability or health can enter. Thousands of “weekend warriors” are willing to run “an hour or so” to compete in a 10K, regardless of the ambient temperature, sun and humidity conditions or their health or conditioning. These *less than perfect conditioned athletes* can fall victim to the effects of exertional heat stress and all its consequences. In 1985 at the Rochester Lilac Festival 10K, a runner died of heat stroke and several were hospitalized. A doctor and retired Marine running the same race recognized the symptoms of heat stroke and saved the lives of several people by grabbing popsicles from a vendor and using them to cool the collapsed runners before transport to the hospital. ***Dehydration is not usually an issue during a 10K. Depending on conditions, heat stress and heat stroke are.***

Swollen Hands and Feet

Athletes have commented that during certain events, particularly those with high heat and humidity, their hands swell a substantial amount. So much so that they appear bloated and are very painful. Excess fluid in the hands, arms, legs or feet is called **peripheral edema**. There is huge discussion on the internet involving swollen hands (hand edema) and feet with varied opinions and explanations ranging from too much swinging of the arms (centrifugal force), holding the hands down (effect of gravity and poor venous return) to too much water and/or salt to too little water and/or salt, increased blood pressure or a combination of several effects. We know that the swelling is a result of excessive fluid accumulating in the hands. Edema seems to occur less in the feet due to the restrictive nature of socks and shoes. Athletes report that supplementation with electrolyte tablets during their runs greatly reduces this. Other athletes report that too much salt increases blood pressure forcing more water into the extracellular spaces. Capillary permeability may also play a role. When the body becomes very hot, extra fluid is distributed outside the capillaries near the skins surface in an attempt to cool down the system. Athletes have reported that although their hand swelling returns to normal after a race, they are then more prone to swelling under milder conditions and even during sleep. This would seem to support a connection between capillary permeability and possible damaged capillaries in the hands, which takes weeks to months to heal completely.

Omega 3 fatty acids, present in high levels in Flaxseed oil, may be of help. These essential fatty acids act to reduce inflammation and strengthen capillary walls. Our diets are generally deficient in omega 3 fatty acids which have many health benefits. Barlean's high lignan cold pressed organic flaxseed oil is a good choice. One tablespoon contains 6200 mg of Omega 3, and 1800 mg Omega 6 fatty acids. In order to incorporate the Omega 3 fatty acids into the cellular membranes, the flax oil must be used for several months.

Pomegranate is another interesting substance that can benefit the circulatory system of athletes and non-athletes as well. It has been called a *super-antioxidant* because it can decrease LDL, raise HDL and actually dissolve arterial plaque. The end result is improved circulation. After about six months the first indication of improved circulation may be that your feet do not get as cold anymore in cold weather. For maximum benefit, use a concentrated extract such as *Naturally Pomegranate*.

Nature of Sweat ^[12]

Contracting muscles produce mechanical energy (movement) and a great deal of heat. This heat must be removed or the body will overheat. The hypothalamus in the brain is the control center for initiating mechanisms to dissipate this heat. Thermal receptors in the skin as well as the temperature of the blood moving through the hypothalamus are the body's "heat detectors". When activated, each of the 3 million coiled sweat glands which are located in the deep skin layer secretes sweat from the interstitial fluid that surrounds them. As this fluid deposits on the skin for evaporation, the circulatory system supplies additional fluid to replace that lost from sweat, always attempting to maintain plasma osmolality and sodium at constant levels. The plasma fluid volume and the interstitial volume which in total are called the extracellular fluid volume are the body's sweat reservoirs. Both reservoirs vary in proportion with the individual's weight. From the table below we can easily see that a light weight individual does not have the reserve capacity of a heavy person. Following that logic, a child has little sweat reserve fluid capacity.

Extracellular Fluid Volumes			
Weight Lbs	Weight Kg	Plasma Volume	Interstitial Volume
50	23	950 ml	5 Liters
75	34	1430 ml	7 Liters
100	45	1905 ml	9 Liters
125	57	2380 ml	11 Liters
150	68	2860 ml	14 Liters
175	79	3330 ml	16 Liters
200	90	3810 ml	18 Liters
225	102	4290 ml	20 Liters
250	113	4760 ml	23 Liters
Plasma volume is 42 ml/kg ^[13] Interstitial Volume = 20% of body weight			

Because the level of sodium in sweat is less than that in the blood, as sweating continues the sodium levels in both the plasma and interstitial spaces increase. This increases the osmolality, causing ADH to be released and the thirst mechanism to kick in. What is the effect of ingesting salt? When you eat a salty meal, you become thirsty and feel a strong desire to drink fluid, but not just any fluid, fluids without salt. The level of sodium in isotonic blood is about 3200 mg/l. If you eat about 3 grams of sodium, in order to maintain a balanced osmolality, you will need to consume about a liter of sodium free liquid, because the 3000 mg sodium plus a liter of say water, is roughly equal to the normal level of sodium in your blood. If you were to drink a liter of tomato juice, you will be taking in about 2800 mg of sodium but you will also be taking in a liter of fluid. If you did not consume any added salt you may not get very thirsty because you have balanced the sodium with liquid. But regardless of the way you consumed the salt, you now have a liter (and about 2 pounds) of fluid in your body. You may feel a little bloated until the kidneys start excreting the salt and the water from the tomato juice.

Pre-Race Hydration

In order to reduce the severity of dehydration during the race, many professional associations recommend drinking about 16-20 ounces of fluid no closer than two hours before the race. That will allow time for absorption and urination before race time. They also recommend about 8 ounces of fluid, ten minutes before the race. Using the same logic as in the above discussion, it makes sense to have sodium in the fluids consumed two hours before race time to enhance retention of the fluids. For the best osmotic retention effect however, the sodium would have to be near that of the plasma, meaning tomato juice or something similar. Remember; never use something new on race day. Try new fluids or foods in your practices leading up to the big day.

Heat Risk Factors

- **Obesity:** Obese individuals are 3.5 times more likely to suffer heat stroke than non-obese athletes. Fat is an insulator and poorly conducts heat to the skin surface for dissipation. Obese individuals should not run marathons or 10K races.
- **Vasoconstrictors:** Many cough and cold medicines contain decongestants such as pseudoephedrine, or phenylephrine which are vasoconstrictors. These constrict the blood vessels near the skins surface, significantly reducing the body's ability to dissipate heat by evaporative cooling. Use of certain weight loss products from 1994-2004 containing the vasoconstrictors ephedra or ephedrine resulted in hundreds of deaths, many occurring during or just after work-outs and many involving heat stroke.
- **Heath Conditions:** High blood pressure and beta blockers used to control blood pressure, reduce the hearts ability to pump hard, thereby reducing cardiac output under intense athletic conditions. Uncontrolled diabetes, kidney disease and a host of other medical conditions may make entering an endurance event unadvisable. Participants are encouraged to have a complete physical and a discussion with their physician before attempting any endurance race, including a 10K.
- **Low salt diets** prior to the race reduce the body's sodium reserve sodium capacity.
- **Low carbohydrate diets** ^[14] reduce the body's glycogen stores and its reserve energy capability. In a study of athletes on low carbohydrate diets compared to normal diets and high carbohydrate diets, time to exhaustion on a bicycle ergometer was 180 minutes on the high carbohydrate diet vs. 70 min on the low carbohydrate diet.
- **Non-steroid Anti-inflammatory drugs** like Ibuprofen can cause the body to retain water, increasing the possibility of hyponatremia especially in women.
- **Diuretics** which are often used to remove excess fluid as a first step in the control of high blood pressure and congestive heart failure decrease the (ECF) extracellular fluid volume. The ECF volume which is about 25% of body weight is the main fluid reservoir for sweat.

Hyperthermia/Heat Stroke or SIADH?

- **SIADH:** Vomiting, then disorientation, drowsy confused agitated behavior, followed by seizures, coma, brain damage and death from cerebral edema.
- **Heat Cramps:** are muscle spasms, especially in the stomach or legs after intense physical activity, and are typically related to a loss of sodium through intense sweating. Athletes with the highest sweat sodium losses tend to experience heat cramps much more than athletes with lower sodium sweat losses. Additional sodium supplementation may be needed.
- **Heat Exhaustion:** Symptoms include dizziness, weakness, thirst, uncoordination, stomach/muscle cramping (from lack of salt), nausea and sweating, cold/clammy skin, and normal body temperature.

- **Heat Stroke:** Symptoms include confusion, combativeness, bizarre behavior, dizziness/fainting, staggering (like stupor), absence of sweating, strong/rapid pulse, delirium, coma, brain damage from 104° and higher body temperatures, and death.

Symptoms of Hyperthermia can be similar to SIADH. A mistake in diagnosis can mean permanent brain damage or death. Both can be present, but with SIADH, additional fluids can kill you! Rapid determination of plasma sodium aids in proper diagnosis and can save lives.

Field Dehydration Tests: Urine Specific Gravity

In order to reduce the incidence of dehydration and its consequences, coaches and athletic trainers are using urine concentration as an indication of dehydration. They frequently use color, noting that a straw or clear color indicates adequate hydration, while a dark yellow or whisky color would indicate dehydration. Urine specific gravity is also used.

“Urine specific gravity, measured by refractometer can provide a quick and reliable estimation of dehydration”

Dehydration Indicators

- Urine Specific Gravity over 1.020
- Urine osmolality greater than 700 mOsm/kg (a valid but impractical tool)
- Plasma osmolality greater than 290 mOsm/kg (an excellent but impractical tool)

National Athletic Trainers Association – Dehydration Cutoffs ^[2]

- Well Hydrated: Urine Specific Gravity (USG) < 1.010
- Minimally Dehydrated: USG 1.010-1.020
- Significantly Dehydrated: USG 1.020-1.030
- Seriously Dehydrated: USG > 1.030

But these “indicators” assume that the kidney is properly retaining and excreting fluid. That does not occur with SIADH. With SIADH the urine will become concentrated as the body swells with excessive fluid.

In Wrestling, “Cutting Weight” Can Kill You!

The NCAA now determines that wrestlers are adequately hydrated if their urine specific gravity is 1.020 or less. ^[15] This test was implemented after the deaths of three healthy collegiate wrestlers in 1997. In order to wrestle in lighter weight classes, the wrestlers attempted to lose several pounds within the 24 hour period before the weigh in. This was done by a combination of almost total fasting along with intense exercise, while wearing a vinyl suit, in a sauna or warm room. The resulting acute dehydration and hyperthermia led to cardiorespiratory arrest and death from hyperthermia or rhabdomyolysis. ***Before collapse all wrestlers felt sudden extreme fatigue, the inability to communicate, and difficulty breathing.*** Elevated sodium and urea nitrogen, elevated temperature (in one case 108° F) and myoglobin (from the rhabdomyolysis) were noted. ^[16]

Hyponatremia among Boston Marathon Runners ^[17]

The death of a physically fit female marathon runner in the Boston 2002 marathon from cerebral edema and the hospitalization of several others resulted in an investigation of hydration recommendations and the publication of the investigation in the 2005 New England Journal of Medicine.

2002 Boston Marathon: “hyponatremia has emerged as an important cause of race-death and life threatening illness among marathon runners

- Definitions
 - Hyponatremia: Serum Sodium < 135 meq/l
 - Severe Hyponatremia: Serum Sodium < 130 meq/l
 - Critical Hyponatremia: Serum Sodium < 120 meq/l
- 488 runners provided blood at the finish line
 - 13% were hyponatremic (22% of women and 8% of men)
 - 3 runners had critical sodium levels: 119, 118 or 114 meq/l
- Predictors of Hyponatremia
 - Female sex, drinking over 3L of fluids, a race time over 4 hr, body mass index less than 20, increased frequency of voiding and especially ***weight gain during the race***
- ***“No association was found between the type of drink consumed (water/sports drink) and development of hyponatremia – probably because most sports drinks are hypotonic and have 1/5th the amount of sodium found in the blood”***

Sodium Status of Collapsed Marathon Runners ^[18]

As a follow-up to the study of the 2002 Boston Marathon runners, sodium levels and osmolality from 140 collapsed runners of the 2003 Boston Marathon were measured. This was an excellent study because all collapsed runners were tested. In previous studies, runners were tested at the finish line. This did not account for sickened runners on the course that did not complete the race.

Citing 250 recent cases of hyponatremia and 7 deaths, the International Marathon Medical Directors Association, issued the ***only drink 400-800 ml/hr*** hydration guidelines in 2003. The results of this study reflect the new recommended fluid consumption guidelines which were known before the race.

Qualifying times to participate in the Boston Marathon are generally less than 3 hr, 30 min. Other than Olympic events, The Boston Marathon stands alone in requiring a qualifying time in order to participate. Although there were no deaths in the 2003 Marathon, we now seem to have a mix of both hyponatremia and hypernatremia. This makes sense because runners are now drinking less. In my opinion, it is difficult to interpret these results because we still don't know exactly how much fluid each runner consumed. Drinks are handed to them in paper cups while they run by. How many cups are taken and how much fluid is actually ingested?

- 25% were hypernatremic (Sodium > 146 mEq/l)
- 12% were hyperosmolar (Osmolality > 296 mOsm/kg)
- 6% were hyponatremic (Sodium < 135 mEq/l with one < 125 mEq/L)
- 16% were hypo-osmolar (Osmolality < 280 mOsm/kg)
- 7/9 of the hyponatremic runners had sample times (when they collapsed) ranging from 5 hr 50 min to 7 hrs. They were the slower runners.

Understanding Cerebral Edema

Cerebral Edema is an excess accumulation of water in the brain which can be due to any of a number of causes including excessive water consumption, SIADH, trauma, high altitude exposure, stroke, hypoxia, cardiac arrest, allergic reactions, certain drugs, and several other causes.

Headache with decreased level of consciousness (changes in awareness of surroundings or self, memory problems), nausea or vomiting, unequal pupils or sluggish response of pupils to light are ALL early but important signs of increased cerebral pressure and cerebral edema.

Fixed dilated pupils, loss of gag reflex and bradycardia are signs of very high cerebral pressure, caused by significant cerebral edema and indicating possible permanent brain injury. Death often follows. ^[19]

How Cerebral Edema Kills

- The total volume of the three elements within the skull:
 - Brain 1400 ml, CSF 150 ml and Blood 150 ml
- Is constant at all times because the skull cannot expand
- If any of the three expand, the volumes of the other two must decrease
- If the fluids increase, the brain swells, the accommodative systems fail and intracranial pressure rises exponentially
- Excessive ICP (Intracranial Pressure) causes a reduction in cerebral blood flow throughout the brain. The resulting widespread ischemia (lack of blood flow) produces brain death

Cerebral Edema: Diagnosis

The clinical differentiation of dehydration from over hydration in a collapsed athlete can be difficult – a mistake in diagnosis with subsequent infusion of normal saline can result in increasing the severity of the cerebral edema and death.

Rapid point of care determination of serum sodium in sickened endurance athletes is critical – and usually not available. Even when brought to the emergency department, electrolyte levels are not always ordered on collapsed athletes.

In a study of 50 collapsed marathon runners brought to the hospital ED for treatment, only 37 had electrolyte levels performed and 21 of these (56%) were hyponatremic. ^[20]

Pulmonary Edema ^[21]

The retention of excess fluids and the resulting hyponatremia results in the movement of these fluids into the lungs. In many cases, both cerebral edema and pulmonary edema are present and in fact the pulmonary edema may be a sign of the coming cerebral edema. Lung function and oxygen exchange are severely impaired with oxygen saturations typically less than 70%. The additional oxygen needed to perform endurance sports (or any sporting activity) is not available and the runner eventually collapses. Before the collapse, there are clues to the onset of pulmonary edema. Runners should be aware of them to minimize the occurrence of both pulmonary and cerebral edema and their possible dire consequences. In a study of 7 collapsed marathon runners with pulmonary edema, all were nauseous, vomiting and were ***coughing up large amounts of frothy pink sputum.***

Treating Hyponatremia ^[22]

After the correct diagnosis has been made, in order to prevent brain injury it is critical that the sodium level be increased slowly. The speed of the correction depends on the initial sodium level. Although websites are available to help in the calculations, this is a very serious medical condition which must be treated carefully in hospital. Evaluating electrolyte and water balance is complicated. Underlying diseases may also be at work.

The screenshot shows a web browser window with the address bar displaying http://www.globalrph.com/hypertonic_saline.htm. The page content includes a blue header for the "Hypertonic and Normal Saline Infusion Calculator" with a copyright notice for GlobalRPh Inc. Below this, there are input fields for "Patient weight: 70 Kg", "Male", and "Current Na+ level: 130 meq/L". A section titled "Hypertonic Saline (3%) calculator" contains explanatory text and a "Target sodium level using 3% saline: 120 meq/L" field with "Compute" and "Reset" buttons. Another section, "Normal Saline (0.9%) Infusion Calculator", has fields for "Target Na+ level: 140 meq/L" and "Maximum rate of increase: 0.5 meq/L/hr" with a "Compute" button. At the bottom, a blue bar indicates "Estimated Body Water Compartment Volumes - for patient data entered above".

Updated Fluid Recommendations: Position statement from the International Marathon Medical Directors Association, July 2006 ^[23]

We have included all the key points from this article because of their importance.

- **Blanket fluid guidelines with fixed ranges will not protect the diverse population of runners participating in athletic events.**
 - The 600-1200 ml/hr was based on elite male athletes, the current 400-800 ml/hr protects smaller mainly female athletes from overdrinking
 - The three main factors governing fluid loss during exercise are body weight, running speed (metabolic rate) and ambient temperature
- *When body fluid losses exceed 2% body weight, performance decreases and the cardiac system is strained*
- *Thirst is stimulated with body water losses of 1.7-3.5%*
- *During intense exercise humans voluntarily only replace up to 75% of sweat loss. Abdominal cramps, nausea and vomiting result when athletes try to match sweat losses 100%*
- **Drinking to thirst will preserve plasma osmolality and maintain intracellular volume and homeostasis.** Thirst, the strong desire for water, is associated with dryness, irritation and an unpleasant taste in the mouth.

- **Thirst and ADH (vasopressin) are closely related.**
 - The threshold for ADH release is a plasma osmolality of 280-285 mOsm/kg
 - The threshold for the thirst response is 290-295 mOsm/kg
 - This is an evolutionary design that liberates people from constantly seeking water
- **Humans respond to sodium increases with vasopressin secretion, thirst and water intake when the plasma osmolality is well within normal ranges – To assume that thirst in an “inaccurate index” of fluid balance during exercise contradicts evolution.**
- **The body defends plasma osmolality and volume over body weight.** This was documented in 1933 when it was noted that humans only drink enough to maintain a constant osmolality, not body weight.
- **Data from multiple endurance studies indicate that:**
 - Athletes who lose 2-4% body weight maintain post race sodium and osmolality (+- 3 mOsm)
 - Athletes that lose over 4% body weight have elevated sodium levels
 - Athletes who lose less than 2% body weight experience a decrease in sodium
 - **Athletes that gain weight progress into hyponatremia**

Sports Hydration '06 Opinion: “Because the degree of weight loss or gain is so critical to the development of dehydration or hyponatremia, athletes need to understand their unique fluid consumption patterns and weight losses during endurance events. Athletes should weigh themselves before and after intense practice sessions and calculate fluids consumed and percent loss. Scales should be accurate and allowances made for sweat weight in clothing, fluids consumed and voiding.

For example, athletes losing only 500 ml/hr through sweat should not be drinking more than 500 ml/hr during the race“

- **Cardiac Effects and Dehydration**
 - Advocates of 100% fluid replacement argue that stroke volume decreases and heart rate increases with as little as 1% fluid loss
 - This is the body’s natural response to dehydration and through this mechanism – cardiac output is maintained. Cardiac output begins to be affected when fluid loss exceeds 3%. At 4% water loss, fluid compartment water shift cannot maintain osmolality and external fluid is needed
 - **Performance and cardiac effects are clearly demonstrated when body water loss exceeds 4%**
- **Sodium, Fluid Balance and Sports Drinks**
 - The plasma volume contraction which occurs during the athletic event to maintain plasma osmolality will return to normal within 24 hrs as sodium containing foods are ingested
 - **Including sodium in sports beverages is an aid to restoring plasma volume and does not prevent the development of Exercise Induced Hyponatremia**
 - There are no studies that document that sodium ingestion during exercise provide a performance benefit

- There are several studies that link sodium ingestion before and during exercise with negative physiologic and performance effects including:
 - Increased body weight, heart rate and temperature
 - Reductions in lung vital capacity, expiratory volume
 - Leg tightness and increased fatigue at maximum effort

Several athletes I spoke with strongly disagree with these sodium recommendations. They stated that sodium supplementation during the race reduced leg cramping and seemed to help them finish marathons with less dehydration.

Sports Drinks: Physiology, Evaluations, Formulations, Recommendations

Hydration and Performance ^[30]

How can you argue with the following statements from the Gatorade website?

Studies have shown that athletes who hydrate with Gatorade outperform athletes who hydrate with water in key performance areas including the ability to exercise longer before succumbing to fatigue, maintaining a faster sprint speed in the second half of the competition, and exhibiting higher explosive power both overall and later in exercise.

Over 40 years of testing and lab results have proven that no other sports drinks gets absorbed faster than Gatorade's proprietary formula of carbohydrates and electrolytes, making it the optimum fluid and electrolyte replacement beverage. If it hasn't been proven in the lab to improve hydration performance, then it is not in Gatorade.

Hydration research over the years however has resulted in confusion and conflicting recommendations. The main points of discussion and contention that we seek to address are:

- **Fluid volume consumed during the event: 400-1500 ml/hr?**
- **Sugar concentration in the sports drink: 2-10 %?**
- **The types and mixes of sugars used: Glucose, Fructose, Sucrose, HFCS, Maltodextrin?**
- **Sodium concentration in the sports drink: 232-845 mg/l?**

Muscles, Energy and Work

Before we discuss our osmolality test results and start commenting on sport drink formulations and recommendations, we must have a basic understanding of how our muscles utilize energy.

Carbohydrate Energy Reserves – 80 kg Person ^[31]

- Plasma Glucose: 3 gm - 12 Calories
- Liver Glycogen: 100 gm – 400 Calories
- Muscle Glycogen: 400 gm -1600 Calories

During intense exercise, to maintain energy to the muscles, the body will deplete the blood glucose first, then the glycogen. Once glycogen is depleted, the body will start to break down muscle protein for energy and in the process produce urea. Depending on the intensity of the exercise, the body may also oxidize fats for energy. The body will attempt to maintain a normal glucose level by utilizing this stored energy.

A two hour intense exercise period depletes the normal stored supplies of glycogen forcing the body to utilize muscle and fat for energy. Once the muscle glycogen stores have been depleted it takes at least 24 hours to replace the glycogen provided that the diet after the event is high in complex carbohydrates and foods with a high glycemic index.

It is potentially dangerous to engage in intense prolonged exercise while on a low carbohydrate or starvation diet. The body will have insufficient glycogen stores and be forced to use protein and fat for energy. Performance will be greatly reduced and the high circulating ketones can produce a dangerous metabolic acidosis. This is especially true if the body is already in a mild ketosis as a result of the low carbohydrate diet.

Carbohydrate Loading ^[32]

By combining a variable carbohydrate diet with exercise it is possible to dramatically increase stored muscle glycogen, thereby improving endurance performance for the event. Typical muscle glycogen stores can be increased from the normal 1.7 gm per 100 gm of muscle to 4-5 gm per 100 gm muscle! Beginning 6 days before the event the athlete moderately trains using only the muscles required for the event while eating a diet low in carbohydrates (60-100 gm). This depletes the muscles of glycogen. Then three days before competition the athlete switches to a high carbohydrate diet (400-700 gm, 60% carbohydrates) and maintains this until the pre-competition meal. Side effects include weight gain from the extra glycogen and the water attached to it (which is also stored). Athletes should check with their coach and physician before attempting this.

Sugar Content

Carbohydrates/Sugars in sports drinks are intended to provide energy, replacing the blood glucose which is used during strenuous physical activity. This is important in order to delay exhaustion and keep the athlete at peak performance.

After the glucose is used up, the body taps into glycogen for energy. After 30 minutes of intense activity, some individuals are glycogen depleted. The body then starts breaking down plasma protein for energy. The net result is urea/ammonia production which is evident by odor produced in the resulting sweat. Ingestion of a 16 oz sports beverage, 90 minutes before the activity can greatly reduce this protein breakdown. A high carbohydrate candy bar also works. However if a 30-60 minute intense gym workout is depleting the individuals glycogen to that extent, he or she should decrease the intensity of the workout.

Countless references state that the optimal carbohydrate (sugar) content of sports drinks is 6-8%. Athletes I spoke with felt that this is too high and that 4% is more reasonable to prevent cramping and other gastrointestinal problems.

Gastric Emptying ^[34]

The rate of gastric emptying (how fast stomach contents can pass into the small intestine) is critical and is in fact ***the limiting factor for rapid absorption of sports drinks***. Plain water empties at the fastest rate, which for most people engaged in intense exercise is about 800 ml's per hour. Many medical/scientific articles followed Edward Coyle's original 1978 article on sports drinks and gastric emptying. Without knowing the associations between the researchers and the sports drink manufacturers, it is difficult to weigh the significance of each article. *Gastric Emptying Rates for Selected Athletic drinks* by Coyle noted that Gatorade which contained a 4.5% sugar solution of glucose/fructose (at the time), 23 mEq/l sodium and a measured osmolality of 349 exhibited a 35% decrease in gastric emptying compared to drinks containing 1.0 or 2.5% sugar and a 40% decrease when compared to plain water.

Many published gastric emptying studies involve indoor cycling under controlled conditions using relatively large amounts of ingested fluid. Real world conditions should attempt to duplicate marathon running. 400 ml of ingested fluid sloshing around the stomach during a run may not have the same gastric emptying rate of the same amount of fluid consumed by a stationary cyclist!

Conflicting Gastric Emptying Articles

- Simple Carbohydrates (Glucose, Fructose, and Sucrose) delay gastric emptying in proportion to their concentration in the sports drink.
- A 6% Glucose-electrolyte solution given to healthy male volunteers emptied at a rate of 1090-1250 ml/hour. ^[35]

- 600 ml solutions of 2%, 4% or 6% glucose were given to 6 healthy men. The 2% solution emptied at the same rate as water; however glucose solutions of 4% and 6% delayed gastric emptying.^[36]

Since gastric emptying appears to be so critical to the absorption of sports drinks or any nutrition for that matter, we need to understand how the stomach and intestine function in this respect.

Research has shown that the stomach expands to accommodate the volume of fluid put into it (up to a point). The maximum volume a non-obese adult stomach can hold is 900-1300 ml, (30-44 oz).^[37] But a stomach that full is a burden to an athlete's performance. Since the stomach can only empty at about 800 ml's per hour during a running event, it is just not possible for most athletes to consume more than 800 ml's of fluid per hour without hurting their performance.

Carbohydrate Metabolism

The body can only oxidize 60-70 gm of carbohydrates per hour. There is no reason therefore to consume any additional carbohydrate per hour during an event. Studies dealing with carbohydrate metabolism and energy production involve measuring oxidation rates. The athlete consumes the test carbohydrate at a very high rate (typically over 1 gm per minute) and the oxidation rate from this consumption is measured. Again, many of the studies involve stationary cycling and as such will indicate the maximum possible capacity but not the practical capacity when running.

- Cycling athletes consuming sports drinks containing sugar carbohydrates at a rate of 1.2 gm/min (0.6 gm sucrose + 0.6 gm glucose) oxidized this sugar solution at a rate of 1.13-1.27 gm/min. This compares to an oxidation rate of 0.73-0.81 gm/min when just glucose was consumed at the same 1.2 gm/min rate. A total of 144 gm was consumed over the 120 min exercise. When the glucose/sucrose solution was consumed at a high rate of 2.4 gm/min, the oxidation stayed the same at 1.2 gm/min.^[38]
- Cycling athletes consuming a sports drink containing Maltodextrin 1.2 gm/min + fructose 0.6 gm/min oxidized these sugars at a rate of 1.43-1.57 gm/min compared to 0.98-1.14 gm/min for 1.8 gm/min of maltodextrin alone.^[39]

Again these studies illustrate that maximum oxidation rates, and hence energy availability are produced when fructose is combined with some type of glucose containing sugar. In addition, they show that the body just cannot utilize carbohydrates much in excess of about 70 gm per hour.

Sodium Levels

The following table is provided to illustrate the relative concentrations of sodium in the body as compared to fluids which have been used for sodium replacement. The current thought is that it is impossible to replace all the sodium lost during a high endurance event. However, to maintain energy and performance, it is necessary to replace glucose during the event. The majority of the sodium lost during the event should be replaced within the twenty-four hours following the event.

Solution	Sodium Level *
FDA Product Label "Very Low Sodium" < 35 mg/8 oz	148 mg/l
Lowest Sodium Sweat Concentration	230 mg/l
Powerade Sports Drink 55 mg Sodium/8 oz	232 mg/l
Average Sodium Sweat Concentration	400 mg/l
Gatorade Thirst Quencher Sports Drink 110 mg Sodium/8 oz	465 mg/l
FDA Product Label "Low Sodium" < 140 mg/8 oz	592 mg/l
Gatorade Endurance Sports Drink 200 mg Sodium/8 oz	845 mg/l
Pedialyte	1035 mg/l
WHO Cholera Diarrhea Solution	1725 mg/l
V8 Vegetable Juice	2000 mg/l
Highest Sodium Sweat Concentration	2300 mg/l
Life Threatening Hyponatremia (Na: 115 meq/l)	2645 mg/l
Campbell's Tomato Juice	2833 mg/l
Normal Plasma Sodium (135-145 meq/l)	3105-3335 mg/l
Normal Saline (0.9% NaCl) about 300 mOsm/kg	3542 mg/l
Swanson Chicken Broth (960 mg per cup)	4000 mg/l
Hunts Tomato Sauce	5250 mg/l
Hypertonic Saline (3% NaCl)	11,806 mg/l
Sodium in Ocean Water (3.5% Salt)	13,700 mg/l
* All levels have been converted to mg/l to allow easier comparison. 8 oz is normally considered to be 240 ml, but it is really 236.6 ml. One ounce = 29.573 ml ¼ level teaspoon of salt weighs 1400 mg and contains 550 mg of sodium.	

Sodium Levels: Popular Sports Hydration Beverages

- Powerade: 232 mg/l which equates to 10 mOsm/kg
- Gatorade Thirst Quencher: 465 mg/l which equates to 20 mOsm/kg
- Gatorade Endurance: 845 mg/l (Introduced in 2004) which equates to 37 mOsm/kg

In summary, the levels of sodium in all popular sports drinks contribute a small amount to the overall osmolality of the drink. The sugars are responsible for most of the soft drinks osmolality.

American College of Sports Medicine 1993 Roundtable Discusses Sodium Content of Sports Drinks ^[40]

“How critical is the sodium content of the fluid replacement beverage? Replacing sodium that is lost in diarrhea using a 50-80 mmol/L sodium level is very important in the clinical setting. On the other hand I’m not so sure that sodium is a problem in replacing sweat losses, which tend to be hypotonic in the first place.

During exercise, the sodium deficits are not going to be as large as in diarrheal diseases, making the use of lower concentrations in the fluid replacement beverages justifiable. ... For example how do we reduce the risk of hyponatremia during prolonged exercise such as marathons and Triathlons? Some rough calculations show that ingesting a beverage with 20-30 mmol/L of sodium per hour is adequate to protect against hyponatremia, providing that the athletes ingest about a liter of fluid an hour.”

In my opinion, they seem to be stating that that the level of sodium in a sports beverage is not that critical. The statement that *sweat sodium is hypotonic* is true. In spite of the wide range of sodium levels in sweat (230-2300 mg/l), sweat sodium is **always** at a lower concentration than that in plasma which is 3100-3300 mg/l. Regardless of the type of beverage ingested, it is not possible to replace the sodium lost during a race, during that race. We also know that if SIADH occurs in an individual, any additional orally ingested fluid including sports drinks or even isotonic IV fluids will result in a further decrease in plasma sodium, possibly resulting in cerebral edema and death.

20-30 mmol/L of sodium is equal to 460-690 mg/l. The leading sports drinks supply 232, 465 or 845 mg/L of sodium. If we review the sodium losses from the included studies we can easily see that a loss of 1375-4770 mg per hour is not corrected by ingesting a liter per hour of a drink containing 460-690 mg sodium per liter.

Research has shown that 1200 ml per hour is the maximum amount of fluid most athletes can drink without getting an upset stomach (and those levels are only possible on a bicycle). In addition, to prevent the occurrence of cerebral edema the new hydration guidelines suggest that no more than 800 ml of fluids be consumed per hour.

Gatorade Endurance Formula is Introduced (Gatorade FAQ Site)

- *Gatorade Endurance Formula is a specialized sports drink with a unique blend of five electrolytes designed to meet the needs of elite and endurance athletes during their longer more intense workouts.*
- *Elite and endurance athletes often have greater sweat and electrolyte losses due to engaging in longer more intense workouts. To help these athletes more fully replace the electrolytes they lose in sweat during these longer, more intense workouts, the Gatorade Sports Science Institute, created Gatorade Endurance Formula.*
- *Both Gatorade Thirst Quencher and Gatorade Endurance Formula are scientifically formulated to meet the hydration needs of athletes. For most active people and athletes, Gatorade Thirst Quencher is the appropriate beverage to help replace the fluid and electrolytes lost through sweat and provide energy to fuel working muscles.*
- *However, we know through extensive research that elite and endurance athletes often have greater fluid and electrolyte losses during their longer more intense workouts. For these occasions, Gatorade Endurance Formula more fully replaces what is lost in sweat.*

Discussion

I must say that the science of sports hydration is perhaps the most complex discipline that I have ever engaged in (and I have handled some tough complex issues). For an overall unbiased understanding of this discipline and as a means to improve your overall health and conditioning, I would highly recommend that you purchase and READ ***Sports Exercise and Nutrition*** by William McArdle, Frank Katch and Victor Katch. An excellent book complete with many color, easy to understand charts and graphs.

The Athletes

I have never run a marathon. 35 years ago, I hiked 33 miles in the first "Hike for Hope". I sweated through three years of high school football and loved every minute of it (now). At 52 I feel great after 20 minutes on a treadmill and I am running at a blistering pace of 6 MPH! The goal of this report is to help the athletes who actually have endurance and can struggle and compete in marathons, ultra marathons or triathlons. I salute you!

I spoke with over a dozen athletes who actually run marathons and their comments and suggestions follow. I know it's a small sample but it will have to do for now. First and foremost, runners do not, cannot, and will not consume enough fluids or sodium to replace what they lose during their race, period! It's one thing to consume 3000-5000 calories during the five hour cycling portion of a triathlon, eating everything from peanut butter and jelly sandwiches to granola bars. It's another to drink and eat while running. During most marathons, fluids are available at each mile post. If runners drank one 6 oz cup of fluid (which holds about 5 oz) every mile they would consume about a gallon (3844 ml) over the course of the race. In a four hour race that would be about 960 ml per hour. But runners I spoke with felt that 1000 ml per hour is too much. As they run, the fluid sloshes around in their stomach like the agitator in the washing machine. At a minimum, the weight of a "full stomach" slows their performance. More typically, they become nauseous, have regurgitation and may even vomit. Consuming about 600 ml per hour seems more reasonable to most runners. That works out to one five ounce drink every 15 minutes ($5 \text{ oz} \times 29.5735 = 148 \text{ ml} \times 4 \text{ cups} = 590 \text{ ml}$). And what are they drinking? A lot depends on the temperature and humidity. On a cool day they may only want water. As the temperature and humidity go up, they may alternate between a sports drink and water. Why not drink just sports drinks? Because the sports drinks that are generally available (Gatorade and rarely Powerade or Ultima) give them an upset stomach when consumed as their only fluid. Why don't they drink something else? Again, they drink what is provided at the water stations. Imagine the complexity of providing a dozen or so different drinks and having thousands of athletes try to find "their drink" as they slow down slightly to grab a cup. It's just not practical. Even if they might prefer the sports drink, on a hot day they will take the water because warm sports drinks taste awful. Chilling the drinks sounds like a good idea to them.

Carbohydrate Energy

How about the 30-60 grams of carbohydrates runners are supposed to consume each hour to keep their energy levels up? Difficult to achieve at best. Sports gels can provide 23 gm of maltodextrin carbohydrates per pouch. Although some athletes swear by them, some commented that they give them an upset stomach. "They just stick there, like a piece of steak". Note that energy gels are supposed to be taken with water. If taken with a sports drink, the increased carbohydrate percentage may cause gastric distress. Drinking 600 ml of a sports drink per hour would provide the athletes with 36 grams of fructose/glucose/sucrose sugars. But again, by alternating water with sports drinks, runners are likely taking in only 18 gm of sugars per hour. Athletes need some alternatives to supply the additional 30 grams per hour of sugar/carbohydrate. Runners I spoke with have found some.

- **Fig Newtons:** Easy on the stomach and each 14.5 gm Newton supplies 45 calories, 11 grams of carbohydrates, 6 grams of sugar and 0 gm fat. Nice and small they fit in a bag in your

pocket. Consuming one every 2 miles would provide: about 41 gm carbohydrates and 22 gm of sugar per hour for a 3:30 marathon pace and about 36 grams carbohydrates, and 20 grams of sugar for a 4:00 marathon pace. FYI: RJR Nabisco is sponsoring and providing Fig Newtons for the 2006 Baltimore Marathon!

Running Speed and Aid Stations

Finishing Time	Mile Speed	MPH	<p>Fig Newton carbohydrate and sugar values are based on race speed.</p> <p>For example, at a 4 hr 00 min marathon pace, the athlete is running at 6.6 MPH. If the athlete eats one Newton every 2 miles, he will be eating 3.3 per hour x 11 gm carbs = 36 gm carbs per hour.</p> <p>The faster athlete will be eating more per hour but all runners will consume the same number over the course of the race.</p>
3 hr 00 min	6 min 52 sec	8.7	
3 hr 30 min	8 min 1 sec	7.5	
4 hr 00 min	9 min 10 sec	6.6	
4 hr 30 min	10 min 18 sec	5.8	
5 hr 00 min	11 min 27 sec	5.2	
5 hr 30 min	12 min 36 sec	4.8	
6 hr 00 min	13 min 44 sec	4.4	
6 hr 30 min	14 min 53 sec	4.0	

- **Twizzlers:** They retain their “plastic” non-sticky nature even under hot conditions and are easy to remove from ones pocket. Each 10 gm strawberry Twizzler supplies 8 gm of carbohydrate, 4.5 gm of sugar and only 0.5 gm of fat. Chew carefully to avoid a choking hazard.
- **Sports Beans:** From the Jelly Belly, Jelly Bean Company. Running stores can’t seem to keep these expensive little things on the shelf. Each one ounce (28 gm) bag has fourteen, 2 gm beans providing: 100 calories, 25 gm of carbohydrates, 19 gm of sugar, 80 mg of sodium and 40 mg of potassium. Instructions say to consume with water. Although these are a great sugar and carbohydrate source, the 80 mg of sodium is actually less than the 125 mg supplied by two Fig Newton’s.
- **Flat Coke:** Useful to relief simple nausea and an upset stomach while providing sugar energy. The original remedy for stomach problems was 1-2 tablespoons of Cola Syrup over crushed ice. 5 ounces of flat Coke provides 18 gm of sugar. At 27 gm per 8 ounce serving, Coke actually can supply more sugar than a serving of many candies and should therefore help with any energy depletion problem. Its sugar comes from HFCS-55 which is a mixture of 55% Fructose and 42% Glucose. Note that defizzed Coke was the original sports drink!
- **Salt Potatoes:** Provides high glycemic index carbs along with sodium. Sometimes available at races longer than marathons.

Sodium

Although it is impossible to replace the amount of sodium lost in sweat during the race, partial sodium replacement is possible. If you consume 300 ml of Gatorade Thirst Quencher per hour and 300 ml of water per hour, you are only taking in 140 mg of sodium per hour. Under normal conditions, sodium losses may range from 1100-1900 mg per hour. Under hot and humid conditions, certain athletes have had sodium losses of up to 4800 mg per hour! But partial sodium replacement is important especially in triathlons and similar races and when hot and humid conditions exist. In both these situations the body can be critically depleted of sodium leading to everything from leg cramps to hyponatremia and even death, especially if large volumes of water are consumed.

Electrolyte Capsules

Although many in the medical community feel that using “salt tablets” is unnecessary and may lead to water retention and other problems, elite athletes feel otherwise. These high endurance athletes are in tune with their high sweat and sodium losses over many races. Through trial and error, they have discovered that electrolyte supplementation (for them) is necessary to prevent leg cramps, hand swelling and other low sodium related problems. Depending on your sweat and sodium losses, electrolyte supplements may be totally unnecessary. As I have discussed in this report, each athlete must determine their unique fluid and sodium losses and replacement needs. Although the following electrolyte supplements are have been mentioned specifically by these athletes, there are others.

Succeed – Each capsule contains: Sodium 344 mg and Potassium 21 mg per capsule along with buffers to reduce the acids produced by intense exercise. (Sodium Chloride, Sodium Bicarbonate, Sodium Citrate, Sodium Phosphate, Potassium Chloride).

Endurolytes – Each capsule contains: Sodium 40 mg, Potassium 25 mg, Calcium 50 mg, Magnesium 25 mg, Vitamin B-6 6.6 mg, Manganese 1.6 mg, and L-Tyrosine 50 mg.

Post Race

In the 24 hours after the race, athletes have a range of choices to replace the sodium, everything from salty food to tomato juice. For liquids, the following illustrates the ranges of sodium available:

- Gatorade Thirst Quencher Sports Drink: 465 mg/l
- Gatorade Endurance Sports Drink: 845 mg/l
- Pedialyte: 1035 mg/l
- Tomato Juice: 2833 mg/l
- Chicken Broth: 4000 mg/l

Tomato juice poses an interesting choice. Not only does it contain almost three times the sodium of Pedialyte, one liter contains 1790 mg of potassium along with 42 grams of carbohydrate and 29 gm of sugar.

Energy Drinks and Marathon Running

First, to clear up any confusion, energy drinks are NOT sports drinks. Energy drinks, or “power drinks” as the athletes refer to them, contain caffeine and usually taurine. Introduced by market leader Red Bull, they were originally only available in a 8.3 oz can. The size was purposely kept small because “energy drinks” were never intended for hydration. Well, in a country were bigger is always better, 16 oz energy drinks now represent 50% of the market, and a 24 ounce is also available. In my 2002 scientific journal article *The Red Bull Reality*, I discussed the physiology of energy drinks. Updated in 2004 and 2006, the publication has kept pace with the introduction and marketing of these larger sizes and other trends like an alcohol/energy drink combination. First; the 80 mg of caffeine in an 8 oz Red Bull is about the same contained in a 5 oz cup of coffee, but we don't drink 5 oz coffees! A 16 oz coffee has about 300 mg of caffeine. Cola's have about 35 mg per 12 oz, so at best we have a mild nervous system stimulant in an 8 oz energy drink.

The key is the taurine. Taurine is a cardiac stimulant. In doses of 2500 mg it increases the stroke volume of the heart up to 25% by making the heart squeeze harder. This results in an increased cardiac output, which really means more blood flowing through the body. Does this improve sports performance? I would say yes depending on the sport. After my energy drink article was published, I presented it at several scientific and medical meetings throughout 2002-2004. At these conferences parents told me that their children playing soccer, lacrosse, basketball and hockey scored more and had improved reaction times when consuming one Red Bull as compared to playing without any.

Studies published in 2001 showed improvements in reaction time as well as thinking ability after consuming one Red Bull. Should marathon runners be consuming energy drinks? I am not recommending the use of energy drinks during marathons because marathoners already have increased stroke volumes do to their intense training and larger than normal hearts. But runners are using Red Bull and in fact some blogs discuss mixing it with Gatorade. Although the FDA has not commented on taurine or glucuronolactone, (the other energy drink ingredient present at high levels), the European food commission recommends limiting energy drink consumption to the equivalent of two Red Bulls per 24 hour period. That would limit taurine intake to 2000 mg per day. Note that the label on a 24 oz can of Boo-Koo energy drink containing 3000 mg of taurine states: *“Serving size 8 oz, servings per container 3, do not consume more than 2 servings per sitting”*

Filling in the blanks [April 2007]

I participated in two television news stories related to sports drinks which aired in January and April 2007. The first one was with the crew of RIT's Sports Zone and it aired on ESPN 2 over a dozen times throughout February 2007. The second was a live broadcast on April 25th with Evan Dawson of WHAMTV13 in Rochester. The questions asked during the first interview prompted me to add additional information and explanations to the **SportsHydration-06** write up in February. The WHAMTV 13 was a two part discussion, the first dealing with sports drinks and athletic hydration and the second addressing issues of healthy hydration choices for everyday non sports hydration.

The main discussions in the first story related to sports hydration, over hydration verses dehydration and how to tell if you are over hydrating. In addition Sports Zone wanted to know if it is necessary to drink sports drinks if you are just working out for an hour. My feeling was not really because you can replace the lost fluids right after the workout. I think there might have been a little confusion regarding over hydration. What needs to be understood is that in school sports, the athletes are generally dehydrated and need to drink more. It's only in marathons lasting over 4-5 hours that certain athletes are over hydrated and this can be very serious. They can minimize this by keeping track of their sweat losses in practice and adjust fluid consumption in line with their losses, but never should they exceed their sweat loss. This is done by weighing themselves.

In the second interview I was asked “if I was working out at the gym which I should be drinking Gatorade or Powerade and why”. My response was, Gatorade because it has twice the salt of Powerade, and if you are really working hard and losing say a quart or more of sweat per hour, you will need to replace some sodium at the end and your lost fluid, but you can do that over a few hours after the workout. But I also explained that the sugars in Gatorade Powder are different than the sugars in Gatorade Ready to Drink and that for the best energy in school sports or intense workouts you should be drinking Gatorade powder because it has a higher amount of glucose and glucose is the body's sugar that it uses for energy. [I had found that report by Nutrition Data between the two interviews]. I also stated that athletes who participate in long endurance events over several hours might benefit from Gatorade Endurance because it has twice the sodium of regular Gatorade and four times the sodium of Powerade. But that to prevent dehydration and over hydration you really need to know how much weight you lose in sweat during a workout. We then discussed the idea of pre-hydration and that it might be a good idea to drink a half liter of sports drink a couple of hours before the workout and that depending on the work you do or what you did that day [outside yard work, etc], you may be very dehydrated even before you work-out and that would not be good.

In part two of the second interview we discussed healthy hydration choices and noted that teenagers have switched and are now drinking sports drinks instead of soda pop and parents are even allowing younger children to drink sports drinks at home instead of soda pop or juice. Is this a good idea? I pointed out that yes, if the consumer drinks the exact amount, sports drinks have only 50 calories per serving as opposed to 100 calories in soda, but they don't normally do that. I showed a 20 oz Coke

Classic side by side with a 32 oz Powerade. I pointed out that these are two very popular sizes and in fact although the Coke contains 2.5 servings and the Powerade four, the consumer drinks the whole bottle of each and both have the exact same calories, 240 in each bottle! And in addition, the Powerade has a lot of artificial dyes, and for that matter all sports drinks are very acidic and bad for your teeth. I mentioned that although Propel is acidic, if you drink Propel Calcium, the calcium buffers it out and actually protects your teeth. We then discussed the new fruit water choices, showing over a dozen products and ended by suggesting that parents go and buy several of these new products, reading labels carefully for things like dyes and artificial sweeteners and do a kind of science experiment by having their kids try them without knowing what they are. We then gave them another idea. White grape juice has a great sugar profile with less fructose than apple juice so it does not give kids an upset stomach, but 100% white grape juice is expensive and has too many calories. I displayed two bottles of Welch's White Grape Juice, 100% Juice and their reduced half calorie product. I pointed out that if you dilute the 100% juice in half with water you have an excellent tasting beverage which has no artificial sweeteners [like the reduced calorie product] no dyes and costs half as much.

As a follow-up to Evans interview, I was over at a friend's house. They have two daughters, a six and a seven year old. One plays soccer and also football on a boy's team. She was watching the segment and unknown to me; she regularly drinks Gatorade Fierce at home. After she saw the news story, she asked her mom to buy some grape juice!

Conclusion

To maintain peak performance, while avoiding both dehydration and cerebral edema, endurance athletes must educate themselves regarding hydration choices during and after the event. They should be keenly aware of their own physiology, and monitor fluid consumption more closely, as well as their thirst and body weight during the event. Although it appears that drinking 400-800 ml of fluid per hour will decrease the incidence of cerebral edema, fluid consumption must be balanced with individual needs. What also seems apparent is the need for point of care testing of serum sodium. An accurate sodium level is critical for both appropriate diagnosis and treatment of a sickened athlete. Without a serum sodium level, it is too easy to misdiagnose cerebral edema as dehydration, in which case the resulting treatment could easily kill the athlete.

The i-STAT, an \$8000 portable analyzer from Abbott Diagnostics that produces lab quality results may be the answer. Using whole blood, which allows immediate testing without centrifuging and a CG4+ cartridge, a runner's sodium, glucose, potassium, and hematocrit can be determined within two minutes! A CG8+ cartridge measures the same four parameters plus blood gases. All results are stored in the unit's computer. During a typical large marathon, 200 or so runners may need to be tested over a three hour period. For fast response, twenty i-Stat units may be needed; one per EMT crew. That would allow each EMT crew to triage about three runners per hour.

Our research with both infant rehydration solutions and sports drinks has shown that for optimal absorption from the intestine, the solution should be hypotonic or at the very least isotonic with the blood. Our osmolality tests indicate that many infant hydration solutions and most sports beverages are hypertonic and as such will have delayed absorption. In our opinion, simple reformulation changes would improve the rate of absorption for both types of solutions.

Bio: Jim Wesley is a forensic chemist and toxicologist with over thirty year's laboratory experience. In addition to his hospital and crime lab jobs he taught a graduate course in toxicology and drug analysis for ten years at the Rochester Institute of Technology. He has presented over 50 scientific seminars, several day long workshops, and five keynote addresses and has taught an entire week at the Henry Lee Institute. He regularly trains law enforcement and nurses in the areas of drug identification, including club drugs, drug rape, psychoactive herbs and supplements (legal highs) and forensic digital photography. His presentations are always both informative and entertaining. Contact Jim at jwesley@rochester.rr.com for further information.

Jim wishes to acknowledge and thank the marathoners and triathletes who shared their running hydration experiences with him and provided valuable suggestions regarding hydration and nutrition for endurance events. He also wishes to thank Ken Micciche, Director of Marketing and New Products, Advanced Instruments Inc, for his support in this important research.

Sports Hydration '08

Look for **Sports Hydration '08** near the end of 2007. Sports Hydration '08 will feature test result updates on all sports drinks and infant rehydration solutions available now as well as the complete osmolality database on over 200 soft drinks, waters and juices. We will also be adding pH and titratable acidity to our testing as well as TDS (Total Dissolved Solids).

Suggestions and comments are always welcomed. The health and safety of the public is always my main goal and life's work. - *Jim Wesley*

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