Athlete Benefits in Hydrating with *Alkaline Antioxidant Water*

Water: The Muscle Bath

How it builds muscle: Whether it's in your shins or your shoulders, muscle is approximately 80 percent water. "Even a change of as little as 1 percent in body water can impair exercise performance and adversely affect recovery," says Volek. For example, a 1997 German study found that protein synthesis occurs at a higher rate in muscle cells that are well hydrated, compared with dehydrated cells. English translation: The more parched you are, the slower your body uses protein to build muscle. Not sure how dry you are? "Weigh yourself before and after each exercise session. Then drink 24 ounces of water for every pound lost," says Larry Kenney, Ph.D., a physiology researcher at Pennsylvania State University.
How it keeps you healthy: Researchers at Loma Linda University found that men who drank five or more 8-ounce glasses of water a day were 54 percent less likely to suffer a fatal heart attack than those who drank two or fewer.
Men's Health.com

Hydration Essentials: The Truth About Water

Before the plethora of sports-related drinks and designer fluids flooded the market, there was simply water. Clear and calorie-free, water is basic and unpretentious and flows naturally into an active sport life with no packaging or gimmicks attached. Don't take basic H2O for granted. Carbohydrates may be the premium fuel for your energy tank, but when you are about to train or compete in your sport, your fluid stores should be topped off as well. You can go a few weeks without food but will only survive a few days without water.
Water plays an integral role in the optimal functioning of your body both during training and during rest and recovery. Well-hydrated muscles are high in fluid content— in fact, water makes up 70 to 75 percent of an athlete's muscle tissue. Fat tissue is relatively low in water content, at about 10 percent. Even bones, though seemingly solid, are about 32 percent water. Consequently, muscular athletes will have high water content when adequately hydrated. Water is stored in many body compartments, and it moves freely among these various spaces.

As the predominant component in our body, water performs many important functions:

- About two-thirds of your body's water is stored inside your cells, giving them their shape and form. The rest of the water in your body surrounds these cells and flows within your blood vessels.
- Water is the main component of your blood. Blood carries oxygen, hormones, and nutrients such as glucose to your cells.
- Water provides structure to body parts, protecting important tissues such as your brain and spinal cord and lubricating your joints. When fluids become depleted through sweating, both your cells and blood decrease in water content and volume.
- Muscle glycogen holds a considerable amount of water, and water removes lactic acid from exercising muscles, which can be an advantage to well-hydrated athletes.
- Water aids digestion through saliva and stomach secretions and eliminates waste products through urine and sweat.
- Water is essential for the proper functioning of all your senses, particularly hearing and sight.
- As the primary component of sweat, water plays a major role in body temperature regulation. It enables you to maintain a constant body temperature under various environmental conditions because it allows you to continually make adjustments to either gain or lose heat. Clearly the role water plays in maintaining your overall health is extremely important. That's why you can't live

without water for more than a few days. But the role that water plays in your performance is equally vital. Being even slightly under hydrated dramatically impedes top athletic performance.

Your fluid balance is simply the result of your intake of fluids versus your output of fluids. Intake is the net result of the water and other hydrating fluids we consume, the water in some of the foods we eat, and the metabolic water produced by our bodies. When you are not training, urine output represents your greatest fluid loss, or output, but sweating during exercise can result in significant fluid losses. Fluid is also lost in feces and in the air you exhale; through exposure to warm or humid weather, living in a dry climate, or living and training at altitude all increase fluid losses; and when traveling, especially by plane.

How much water do you need? Most people have heard the oft-quoted recommendation to consume eight 8-ounce cups of fluid (4 quarts, or about 1.9 L) daily, mainly in the form of water. In 2004, when much public attention was focused on dietary water requirements, the Food and Nutrition Board of the Institute of Medicine (IOM) released Dietary Reference Intakes (DRIs) for water and various electrolytes. Because of the large variations in water needs among individuals, the IOM panel established Adequate Intake (AI) levels of 130 ounces, or about 16 cups (3.8 L), daily for men and 95 ounces, or about 12 cups (2.9 L), for women.

But of course daily fluid losses can vary greatly depending on your level of training, whether you are male or female, and your individual sweat rate. The daily fluid needs of active males can increase to 4.75 quarts (4.5 L), but requirements for male endurance athletes can often be in excess of 10.5 quarts (10 L) daily, depending on sweat losses during training, and perhaps slightly lower for women. Estimating fluid requirements beyond the basic AI recommendations is really about replacing fluid at a rate close or equal to your own individual sweat rate and total sweat losses for a particular day of training. Further guidelines for replacing training sweat losses are provided in Chapter 5.

At rest, the fluids your body needs can be slowly replenished throughout the day as you make a conscious effort to drink enough water every one to two hours to replace these fluid losses. You should be aware, however, that climate, clothing, and other factors can affect daily water requirements. While thirst is often thought of as the primary human drive that pushes us to drink, it is important for athletes not to rely on thirst alone but to develop regular drinking habits and behaviors to maintain a good level of daily hydration and monitor their own hydration status. By the time someone becomes thirsty, his or her body has already sensed a decrease in the level of fluids or an increase in sodium concentration. So in reality, you get thirsty only when you have already experienced some fluid loss or alterations in your sodium status, both of which are affected by the prolonged periods of sweating that endurance athletes regularly experience. By then, an athlete's performance level would already have decreased. So for an endurance athlete in training, one of the most important concepts to learn is that it is unwise to rely on thirst only for daily hydration needs. Doing so may result in falling short of both optimal fluid intake and optimal performance or recovery.

About The Author: **Monique, Ryan**, MS, RD, CSSD, LDN, is a seasoned and trusted sports nutritionist with nearly 30 years of professional experience helping elite and age-group endurance athletes and major league sports teams to optimize their nutrition. She is also the founder of Personal Nutrition Designs, based in the Chicago area.

How Professional Athletes Benefit from Alkaline Water

Competitive, elite athletes and sports trainers know that subtle changes in pH can have profound effects on the overall health, feeling of wellness, level of fatigue, pain, weight, ability to train and athletic performance. Muscles work best in a narrow range of Ph. At rest, muscle pH is about 6.9, while arterial blood is about 7.4. When we exercise, the increased use of muscle glycogen for energy produces lactic acid, pyruvic acid, and CO2, which decreases muscle pH. The harder you exercise the quicker your muscles become acidic which leads to fatigue. Accumulation of acid also limits the production of ATP, the energy molecule, and disrupts

enzyme activity that produces energy.

For example, the enzyme phosphofructokinase is the rate-limiting step in muscle use of glycogen. When muscle pH falls below 6.5 it stops working altogether. Acidity also reduces muscle power directly by inhibiting the contractile action of muscle fibers.

"Endurance and elite sports athletes should be concerned about maintaining a healthy pH balance," says Robert Burns, PhD. He notes that lactic acid build-up or hydrogen ion excess is of most concern. As the body metabolizes food, acid waste is created which must be removed or neutralized through the lungs, kidneys (urine) and skin. "pH balance and acid buffering are crucial to human health and slowing the aging process," he explains. Athletes, coaches and practitioners of holistic and traditional medicine are paying more attention to this area. "We may be able to buffer or slow the negative effects that acidosis has on athletes as well as the many disparate maladies that share acidosis as a common thread," he concludes. The use of alkaline water is proving to increase competitiveness and overall performance in world-class athletes. Sports nutritionists also recommend a diet that supports alkalinity. Consuming alkaline water will reduce the accumulation of acidity in exercising muscles, improving workout intensity and recovery time. Former Denver Bronco, Bill Romanowski, was introduced to the power of 'ionized' water late in his career doing anything legal to maintain his competitive edge.

Competitive bodybuilder, *Wade McNutt,* credits the use of alkaline water for motivating him to come out of retirement. He says he has increased his training volume by 2.5 times with decreased recovery time and no muscle soreness. In his opinion, all sports teams should be drinking alkaline water because it will reduce injuries and allow for more efficient training.

In her book, The Chemistry of Success: Secrets of Peak Performance, Susan Lark, MD, talks about the role of acid/alkaline balance in peak performance and health. The following is her assessment of alkaline water: "**The benefits of the alkaline water** created through ionization far exceed just its ability to gently raise the pH of the cells and tissues of the body and to neutralize acids. Because the alkaline water has gained a significant number of free electrons through the ionization process, it is able to donate these electrons to active oxygen free radicals in the body, thereby becoming a super antioxidant. By donating its excess free electrons, **alkaline water is able to block the oxidation of normal tissue by free oxygen radicals.**"
She continues by noting that another significant benefit of the ionization process is that the cluster size of the alkaline water is reduced by about 50% from the cluster size of tap water. "This allows ionized alkaline water to be much more readily absorbed by the body, thereby increasing the water's hydrating ability and its ability to carry its negative ions and alkalizing effect to all the cells and tissues of the body."
"If you are overly acidic an *alkaline antioxidant water* device can provide a safe, gentle and effective way of restoring the pH balance of all the cells in your body as well as providing excess free electrons to act as super antioxidants," Lark recommends.

Most people, including ***most athletes***, do not consume enough alkaline rich foods, such as nuts, fruits, and vegetables. Instead their diets contain high amounts of acid forming foods, such as meat, fish, poultry, eggs and dairy. Because of this dietary imbalance, they may be at risk for increased acidosis that affects overall health and sports performance. Since proper hydration is also a key factor in preventing exercise fatigue, consuming alkaline water before, during and after exercise can help.

About the Authors: ***Susan Lark, MD*** is considered one of the foremost authorities in the fields of clinical nutrition and preventative medicine. She holds a medical degree from Northwestern University Medical School and has served on the clinical faculty of Stanford Medical School. A widely published author on the subjects of health, nutrition and preventative medicine, Dr. Lark advocates the use of alkaline, ionized water. ***Robert Burns Ph.D.*** served as Chief Scientific Officer for pH Sciences from 2003 to 2005. He has directed numerous studies on pH Sciences analyzing relationships between pH balance, health, and athletic performance.

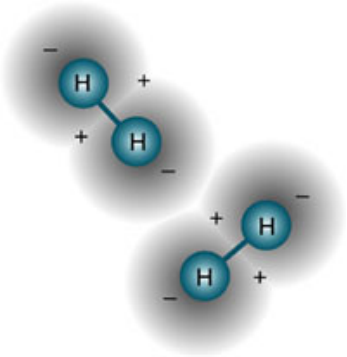
The Hydrogen Story

Browsing the ads in the numerous magazines targeting the fitness community it is curious to note the vast array of similar symptoms which such a diversified conglomerate of nutritional formulas are designed to address. Whether you want to build mass, increase strength, reduce fat, increase energy levels, strengthen your immune system, renew sexual drive, improve performance, stop the aging process, enhance mental alertness, eliminate soreness, or (my favorite), improve your over-all well-being, you can find at least a half-dozen formulations which can help you accomplish your desired goal.

Interestingly enough, very few of them have anything in common; while fewer yet are based upon actual science and none of them contain the one ingredient that your body requires to accomplish all of these tasks. That ingredient is H- (negatively charged hydrogen).

This little known nutrient is, in fact, the smallest element known to exist at this time. In spite of its size, it is indispensable in virtually every chemical reaction in the body.

Nowhere is this more important than inside the cells of our body where tiny organisms, called mitochondria, translate the free electron negative charge associated with the H- molecule into the ATP, which provides the energy necessary to produce growth, repair, and regeneration of the body.
In the latter half of the 20th century, it became apparent that the negative hydrogen ion was not as rare and short-lived in nature on our planet's surface as once thought. Indeed, by the 1990's it became apparent the H-minus ion is ubiquitous in the biochemistry of life forms on earth, and essential to certain key biochemical reactions related to the citric acid cycle (Krebs cycle) in living organisms.



By the late 1990's, it became obvious that several common antioxidants found in plants and animals (Vitamin E among them) function as an antioxidant by acting as a transport vessel for the H- ion, donating it at the right time within living systems to neutralize any of several species of oxygen free radicals (oxidizing radicals), also known as reactive oxygen species (ROS) occurring in tissues or fluids in or around the cells.

It also became generally recognized by the late 1990's that the likely mechanism by which certain key energy-transport molecules in living systems were formed and subsequently regenerated after "being burned" was via donation of H- to the molecule by a donor molecule, the origins of which ultimately traced back to the energy liberated from sunlight during photosynthesis.

In the Absence of an Abundant Free Electron Pool Your Ability to Perform and Recover will be Substantially Limited, Regardless of What Other Nutrients are Present!

The bottom line here is that the free electron associated with the H- complex is necessary as a raw material for the mitochondria to produce energy. The hydrogen to which it is attached is utilized to combust available oxygen to allow us to express the energy, which is produced. Therefore, regardless of the amount of cardio you perform, or the amount of protein, fats, carbohydrates, or any other nutrient you take to enhance your performance you will never experience your full potential in the absence of a rich free electron pool of H- in the body.

For the athlete this translates into two important functions, which will determine their ultimate ability to excel in a chosen sport; PERFORMANCE and RECOVERY.

How Can I Know?

In the absence of a "Matrix Assessment Profile" you may obtain information about the effectiveness of any given nutritional program by using an ORP (Oxidation Reduction Potential) meter to measure the oxidation or reduction power of a substance, usually a liquid.

It is measured in millivolts (mv.) on a scale from -1,200 (most strongly reducing) to +1,200 (most strongly oxidizing). A reading at or below approximately zero (0) strongly, although indirectly, indicates an increasing concentration of the negative hydrogen ion or potential for creating energy.

Why is This Important?

As any athlete knows, one of the greatest dangers and side effects of heavy training is the production of excessive free radicals. These damage the ability of our cells to perform the functions required for repair and regeneration. Biochemically, free radicals are simply substances which steal electrons.
Therefore, if you are training heavy, you are more than likely creating excessive free radicals which are depriving your body of the one substance required to achieve the purpose for which your training was designed.

But it Takes Antioxidants

Medical science has well documented the need for antioxidants to neutralize the unstable free radical activity produced by exercise. If you are a seasoned athlete, you are probably consuming antioxidant complexes as part of your nutritional support program. This most likely consists of antioxidant compounds such as Vitamin C, Vitamin E, Betacarotene, Selenium, grape seed or pine bark extracts, etc.

The Problem With Antioxidants is Twofold:

- No matter how large the antioxidant molecule it gives up only one electron for the purposes of neutralizing free radical activity.
- When an antioxidant donates an electron to neutralize free radicals it becomes a free radical. Of course it is weaker and less harmful than that which it neutralized but, nonetheless, it becomes a free radical.

This process is known as the electron cascade and is the reason for including a broad spectrum of antioxidants in any supplemental nutritional program.

So What Can I Do?

Albert Szent-Gyorgyi, in his original research for which he won the Nobel Prize for his work on Vitamin C,

discussed electron flow in the body. Electrons move but never by themselves. There needs to be a carrier. That carrier is the hydrogen atom with the extra electron in the outer shell.

Free electrons affect the body in a very positive way as the free radicals are neutralized. Since free radicals normally steal electrons from cell walls and DNA structure the inevitable result is abnormal cell function and eventually disease. Science is very clear that free radicals are the basis for many of the major disease processes in the body today. The hydrogen also feeds into the energy cycle of the body providing healthy energy and creating less fatigue.

Stop Sickness before It Starts – Improve Your Biochemical Environment

Getting sick requires that your natural resistance break down. All cells live in the biological fluid. It is the environment in which they function day-to-day. A balanced biochemistry means balanced fluid, which in turn means healthy, vibrant cells. When cells are healthy, sickness can't get a foothold. This is letting the body and your natural defense system do the job it is designed to do … stay healthy!

So, if you are an athlete who has hit a wall in your training, suffers from DOMS, truly wants to experience more energy, less fatigue, or improved mental clarity, see how can this simple hydrogen atom can improve your performance while:

- Fighting free radical damage throughout the body
- Balancing the body's chemistry through the Biological Terrain
- Helping to resist sickness
- Reversing the disease process and slow down aging

Increase Your Resistance and Stay Healthy with intentional supplementation

H-minus ions in foods Some folks decide to eliminate highly processed and heated foods from their diets, and instead, choose to incorporate large amounts of raw foods such as raw vegetative products (fruits, vegetables), and sometimes raw animal products (raw eggs, dairy, fish and meats) as well. Some also choose to start drinking unprocessed and unfiltered water from natural deep aquifers. The very act of switching to such a diet of raw, unprocessed foods drastically increases the availability of the H-minus ion in the daily intake.

Alkaline Antioxidant Water

The most ubiquitous supplemental source of the H-minus ion for the past 45 years in Japan and past 15 years in the USA has been so-called "alkaline ionized water", also known as "micro water", from kitchen countertop water ionizers. This water is more accurately called Alkaline Antioxidant Micro-Clustered Water; which is the naming convention, which most commonly appears in articles in scientific literature to denote this water.

This water is often called "reduced water" due to its reducing, or antioxidant activity, and has been called "micro water" by some commercial vendors due to the fact that the water exhibits a smaller cluster size than "normal" water.

There exist some people who deliberately ingest H- as a nutritional supplement for the health benefits, primarily its advantages as a primal antioxidant or primeval antioxidant, and one with extremely low molecular weight and size, allowing it access to many and varied tissues and levels of biochemical activity. Regardless of the methodology you choose the important facts to remember are that the reproduction of

negatively ionized hydrogen brings us the most powerful antioxidant, a natural alkalizer, an anti-microbial agent, and a way to restore and maintain cellular fluid balance.

The most valuable benefits of seeking out the negative hydrogen substances are improving health, repairing tissue, reducing pain, increasing energy and reversing aging. The cells and the body as a whole are restored to and kept in the healthiest possible state.

About the Author: Dr. Richard A. DiCenso is a published author, international speaker, and complementary care expert. Dr. DiCenso has over 30 years experience in treating the chronic symptoms of Vicious Cycle disorders (VCD). With his extensive experience in "Whole Person Therapy", he is the leading authority in Biological Fluid Analysis.

Athletes and Acid

Why aging, elite, and high performance athletes need to understand and avoid excess acid build up in their muscles, a condition called Sport Induced Acidosis.

Elite and high performance sport athletes continually push at the boundaries of physics, trying to compress time into ever-smaller increments or beat gravity at its own game. In the process, they often redefine what is “humanly possible,” not only for themselves but, in some cases, for all of us.

As every athlete knows, in the sports world a millisecond or the slightest internal or external physical advantage can mean the difference between victory and defeat, a repeat performance or a new world record or personal best. And, unfortunately, sometimes it is a world where athletes destroy their careers, health or reputations trying to dope their way to new physical feats.

Life in the balance

Currently, athletes competing in elite, high level, individual and team sports are breaking performance barriers at a record pace. There are a number of reasons for this: advancements in training, athletic equipment, sports medicine and physical therapy, as well as a deeper understanding among coaches and athletes of human body chemistry and the role nutrition and body chemistry plays in athletic performance. For the purpose of this paper, we will focus on one particular—and often overlooked—physiological and nutritional aspect of maintaining health and athletic performance: control of sports induced acidosis through acid-base balance.

Athletes who are committed to legal, healthful ways of increasing performance, reducing fatigue, and compressing recovery time need to understand acid balance and the negative impact of too much acid. High performance and elite sport athletes should be particularly concerned with maintaining a healthy acid level, as they regularly place themselves under physical and dietary stresses that can lead to imbalances, most commonly lactic acid which indicates excess hydrogen ion (acid) buildup. Whatever your level of athletic intensity, a healthy acid balance can mean the difference between greater athletic achievement or being brought up short by muscle “burn” or cramping.

A pH primer ~ or ~ What Every Athlete Needs to Know About Acid Balance

Proper pH balance is a key component of good health and it is absolutely essential to athletic performance. pH is measured on a 14-point scale, with 7 being neutral. The lower the pH value, the higher the acidity; the higher the pH value, the more alkaline. pH values vary throughout systems in the human body. So, as you might imagine, stomach acid has a very low pH value, ranging from 1.0 to 3.0 while digesting food. Pancreatic excretions are very high in pH value, ranging from 8.0 to 8.3. The pH value of arterial blood in a

healthy human is balanced around the middle of the 14-point scale at a narrow range of 7.35 to 7.45, or just slightly alkaline.

As the body metabolizes fuel (i.e. food), acid wastes are created. To sustain a healthy blood pH balance, acid wastes must be removed from the body or neutralized. The body has numerous ways to flush acid waste out of the system: the lungs vent carbon dioxide; our kidneys filter blood and excrete acids through urine (urine pH value can be as low as 4.5); skin sweats acids out of the system. In addition to its various acid-flushing functions, the human body also has built-in chemical buffers that help to neutralize pH imbalances, including calcium, phosphorus, bicarbonate, hemoglobin, and phosphate cycles in the blood. When, because of diet, intense exercise, and/or aging, we exceed the body's ability to flush out or neutralize acid wastes, acid buildup—sports induced acidosis—occurs.

Crossing the threshold, managing the "burn"

Most serious athletes are familiar with the phenomenon known as "muscle burn." Muscle burn is largely the result of lactic acid, which indicates hydrogen ion buildup in the system and is one effect of excess acid in the blood and tissue. Acid concentration increases when an athlete exceeds what is called the "lactate threshold," the point at which the body can no longer flush or neutralize acid wastes as fast as they are being produced. When an athlete crosses the lactate threshold for a sustained time, acid accumulates in the muscles and can lead to cramping, severely compromising their performance. Contrary to popular belief, lactic acid is not, in and of itself, the cause of acidosis. However, elevated levels of lactic acid in the system are an indicator of excess acidic hydrogen ion buildup in the muscles and blood.

Exercise is not the only contributing factor to acidosis. Aging and diet also play key roles. As we age, our systems that rid the body of acid waste don't work as efficiently. Furthermore, the western world's diet, with its overemphasis on animal protein, fats, processed sugar and flour, is likely a contributing factor in acidosis. Because elite and high performance athletes often burn through exponentially more calories than the average person does in a day (a 175-pound athlete can burn approximately 6,000-8,000 calories in the course of a 60-mile bike race alone), they should be particularly concerned with acid balance and dietary health. Also, the athlete's often-accelerated intake of protein and carbohydrates can produce surplus acid from their metabolic wastes.

Prevention is the Best Medicine

So, how can athletes protect themselves from acid imbalance? A healthy diet is the best place to start. Cutting back on acid-producing foods and beverages such as animal protein, coffee, soft drinks, and wine, can help. But remember: just because a food is chemically acidic doesn't automatically mean it's an acid producing food. (So, for example, citrus fruits actually have an alkalizing effect on the body, as do most acidic fruits and vegetables.) To maintain a healthy acid balance, many natural medicine practitioners recommend a diet comprised of anywhere from a 60/40 to as much as an 80/20 ratio in favor of alkalizing foods over acid-producing foods. However, that's not always easy to achieve—especially for people who don't want to pay obsessive attention to their diet. And, as we discussed earlier, even with the best diet, human beings naturally become more acidic as we age and our metabolic processes slow.

Most people, including ***most athletes***, do not consume enough alkaline rich foods, such as nuts, fruits, and vegetables. Instead their diets contain high amounts of acid forming foods, such as meat, fish, poultry, eggs and dairy. Because of this dietary imbalance, they may be at risk for increased acidosis that affects overall health and sports performance. Since proper hydration is also a key factor in preventing exercise fatigue, consuming alkaline antioxidant water before, during and after exercise can help.

About the Author: ***Robert Burns Ph.D.*** served as Chief Scientific Officer for pH Sciences from 2003 to 2005. He has directed numerous studies on pH Sciences analyzing relationships between pH balance, health, and athletic performance

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Pilot study: Effects of drinking hydrogen-rich water on muscle fatigue caused by acute exercise in elite athletes

Kosuke Aoki[1], Atsunori Nakao[2*], Takako Adachi[1], Yasushi Matsui[1] and Shumpei Miyakawa[1]

Abstract

Background: Muscle contraction during short intervals of intense exercise causes oxidative stress, which can play a role in the development of overtraining symptoms, including increased fatigue, resulting in muscle microinjury or inflammation. Recently it has been said that hydrogen can function as antioxidant, so we investigated the effect of hydrogen-rich water (HW) on oxidative stress and muscle fatigue in response to acute exercise.

Methods: Ten male soccer players aged 20.9 ± 1.3 years old were subjected to exercise tests and blood sampling. Each subject was examined twice in a crossover double-blind manner; they were given either HW or placebo water (PW) for one week intervals. Subjects were requested to use a cycle ergometer at a 75 % maximal oxygen uptake (VO_2) for 30 min, followed by measurement of peak torque and muscle activity throughout 100 repetitions of maximal isokinetic knee extension. Oxidative stress markers and creatine kinase in the peripheral blood were sequentially measured.

Results: Although acute exercise resulted in an increase in blood lactate levels in the subjects given PW, oral intake of HW prevented an elevation of blood lactate during heavy exercise. Peak torque of PW significantly decreased during maximal isokinetic knee extension, suggesting muscle fatigue, but peak torque of HW didn't decrease at early phase. There was no significant change in blood oxidative injury markers (d-ROMs and BAP) or creatine kinase after exercise.

Conclusion: Adequate hydration with hydrogen-rich water pre-exercise reduced blood lactate levels and improved exercise-induced decline of muscle function. Although further studies to elucidate the exact mechanisms and the benefits are needed to be confirmed in larger series of studies, these preliminary results may suggest that HW may be suitable hydration for athletes.

Introduction

Since energy demands and oxygen consumption increase during supermaximal exercise, such as intermittent running, sprints, and jumps, production of reactive oxygen species (ROS) and reactive nitrogen species (RNS) also increase, threatening to disturb redox balance and cause oxidative stress. During normal conditions, ROS and RNS are generated at a low rate and subsequently eliminated by the antioxidant systems. However, a greatly increased rate of ROS production may exceed the capacity of the cellular defense system. Consequently, substantial free radicals' attack on cell membranes may lead to a loss of cell viability and to cell necrosis and could initiate the skeletal muscle damage and inflammation caused by exhaustive exercise [1-3]. Although well-trained athletes suffer from less oxidative stress reduction because their antioxidant systems adapt, accumulation of intense exercise can provoke an increase in oxidative stress [4]. To mitigate oxidative stress-induced adverse events during sports, antioxidant supplementation among athletes has been well documented. Although results of these studies are often contradictory depending on the antioxidant compounds and quantity, some studies demonstrate the beneficial effects of antioxidants on muscle fatigue or performance [5,6].

* Correspondence: atsunorinakao@aol.com
[2]Department of Emergency and Critical Care Medicine, Hyogo College of Medicine, 1-1, Mukogawa-cho, Nishinomiya, Hyogo 663-8501, Japan
Full list of author information is available at the end of the article

Recently, the beneficial effects of hydrogen-rich water (HW) have been described in experimental and clinical disease conditions [7,8]. Although research on the health benefits of HW is limited and there is scant data on long-term effects, pilot studies on humans suggest that consuming HW may help prevent metabolic syndrome [9], diabetes mellitus [10], and cancer patients' side effects with radiotherapy [11]. Since hydrogen is known to scavenge toxic ROS [12] and induce a number of antioxidant proteins [13,14], we hypothesized that drinking HW may be beneficial for athletes in reducing oxidative stress-induced muscle fatigue following acute exercise. In this study, we evaluated the efficacy of hydrogen-rich water on healthy subjects by measuring muscle fatigue and blood lactate levels after exercise. Although further studies are needed to elucidate the exact mechanisms and benefits, this report suggests that hydrogen-rich water might be an appropriate hydration fluid for athletes.

Methods

Subjects

Ten male soccer players aged 20.9 ± 1.3 years old were subjected to exercise tests and blood sampling. None of the subjects were smokers or were taking any supplements/medicines. Each subject provided written informed consent before participation in accordance with the University of Tsukuba's Human Research Ethics Committee. Physical characteristics of the subjects are shown in Table 1. All the players were involved in daily training sessions except the day of experiment.

Generation of hydrogen-rich water

A plastic shelled product consisting of metallic magnesium (99.9 % pure) and natural stones in polypropylene containers combined with ceramics (Doctor SUISOSUI®, Friendear, Tokyo, Japan) was used to produce hydrogen. The product was capable of generating hydrogen when placed in drinking water via the following chemical reaction: $Mg + 2H_2O \rightarrow Mg\ (OH)_2 + H_2$. The magnesium stick or a placebo (a casting-only stick without magnesium) was immersed in mineral water (Volvic®, Kirin Inc., Tokyo) for 24 hours prior to drinking. The final hydrogen concentrations of the placebo water (PW) and hydrogen-rich water (HW) were 0 and 0.92 ~ 1.02 mM, respectively [9,11]. Each subject was examined twice in a crossover double-blind manner, given either HW or PW for one week intervals.

Table 1 Subjects' Physical Characteristics (n = 10)

Variable	Value
Age (year)	20.9 ± 1.3
Height (cm)	172.0 ± 3.8
Body weight (kg)	67.1 ± 5.2
BMI (kg/m^2)	22.8 ± 1.4
VO_2max (ml/kg/min)	53.2 ± 4.9

BMI: body mass index, VO_2max: maximal oxygen uptake.

Dose and mode of administration of hydrogen-rich water

Subjects were provided with three 500 ml bottles of drinking water and instructed to place two magnesium sticks in each bottle 24 hours prior to drinking. Participants were asked to drink one bottle at 10:00 PM of the day before the test, one at 5:00 AM, and one at 6:20 AM on the day of examination. In summary, subjects consumed 1,500 ml of HW or PW.

Protocol

The research protocol started at 6:00 AM. Subjects were given meals between 9:00 PM and 10:00 PM the day before experiments, and fasted overnight. No breakfast was given on the day of the experiments. The subjects were first required to rest in a sitting position for 30 minutes. The exercise test consisted of the following: 1) Maximal progressive exercise test to define maximal oxygen uptake (VO_2max); 2) cycling an ergometer for 30 minutes at approximately 75 % VO_2max (Exercise-1); and 3) Running 100 maximal isokinetic knee extensions at 90 °sec^{-1} (Exercise-2). Blood samples were collected from an antecubital vein just before Exercise-1 (6:30 AM), immediately after Exercise-1 (7:15 AM), immediately after Exercise-2 (7:30 AM), 30 minutes after Exercise-2 (8:00 AM) and 60 minutes after Exercise-2 (8:30 AM).

Maximal progressive exercise test

First, to define maximal oxygen uptake (VO_2max), the subjects were subjected to a maximal progressive exercise test on a bicycle ergometer (232CL, Conbiwellness, Tokyo). The test consisted of a continuous step test beginning at a 30 W load, and increasing by 20 W every minute until exhaustion. The subjects were instructed to ride at 50 rpm/min. Pulmonary gas exchange values were measured using an exhaled gas sensor (AE280S, Minato Medical®, Osaka, Japan) via a breath-by-breath system, and the mean values were calculated every 30 seconds for analysis. We determined that VO_2max was reached when the oxygen consumption reached its plateau [15].

Fixed-load cycling at 75 % (high intensity) of VO_2 max

Before the test started, the subjects rested for two minutes. After warming up at a load of 50 W for one minute, the subjects were instructed to ride at submaximal levels for 30 minutes. Pulmonary gas exchange values were monitored to maintain VO_2max at approximately 75 %. During the experiments, the subjects were frequently verbally instructed to control the range of motion to maintain VO_2max at approximately 75 %.

Maximal isokinetic knee extensions

A calibrated Biodex System 3 isokinetic device (Biodex Medical Systems, New York, USA) was used to measure peak torque (PT) and knee-joint position throughout 100 repetitions of maximal isokinetic knee extension. During testing, each subject was seated on the Biodex system 3 with 90° hip flexion, and restraining straps were placed across the waist and chest in addition to a rigid sternal stabilizer. The dynamometer was motor driven at a constant velocity of 90°/sec. Each subject performed a series of 100 isokinetic contractions using the knee extensors of the right leg from 90° of flexion to 0° (full extension). As the arm of the dynamometer moved up from 90° to 0°, subjects were encouraged to perform maximally for each contraction throughout the full range of motion. Subjects relaxed as the dynamometer arm moved back to 90°. Each contraction and relaxation period lasted one second and the total length of the contraction cycle was thus two seconds. All subjects were able to complete the full 100 contractions.

Measurement of muscle fatigue

To measure muscle fatigue, the widely used First Fourier transform technique (FFT) is utilized to analyze mean frequency of surface electromyogram (EMG) [16]. EMG signals were obtained from the rectus femoris muscle via electrodes connected to a 4-channel frequency-modulation transmitter (Nihon Kohden, Tokyo, Japan). All data were stored and analyzed using the FFT functions in Acknowledge 3.7.5 software (BIOPAC SYSTEM, Santa Barbara, USA). Mean power frequency (MPF) and median power frequency (MDF) were calculated as previously described [17]. MPF shift of the EMG signal toward lower frequencies has been extensively used in static contractions to indicate the development of peripheral fatigue.

Blood test

Blood lactate levels were determined using a commercially available Lactate Pro LT17170 kit (Arkray, Inc., Kyoto, Japan). The concentrations of derivatives of reactive oxidative metabolites (dROMs) and biological antioxidant power (BAP) in the peripheral blood were assessed using a Free Radical Analytical System (FRAS4; Wismerll, Tokyo, Japan). Laboratory tests for creatine kinase (CK) were conducted using standardized procedures at Kotobiken Medical Laboratory Services (Tokyo, Japan).

Statistical analysis

Repeated analysis of variance (ANOVA) tests were used to compare pre- and post-exercise measurements. The F-test with Bonferroni *post hoc* group comparisons was performed where appropriate. Probability values less than 0.05 were considered to be statistically significant. SPSS 18.0 was used to perform the statistical analysis. Since the experiment was planned to have a 90 % power of achieving significance at the 5 % level, the sample size in this model is calculated to be between 8.91 and 9.25 (90 % power and 5 % significance level) in blood lactate levels based on our previous experiences. Therefore, we assumed the sample size would be appropriate for accumulation of preliminary data.

Results

Blood analysis for lactic acid, d-ROMs, BAP and CK

As shown in Table 2, blood d-ROMs BAP and CK levels increased after exercise in subjects in both groups treated with PW and HW. However, there was no statistical difference between the groups. Eventhough the blood lactate level were significantly increased in both HW and PW at 45 and 60 min after exercise, these levels were comparably and significantly lower in the HW than in the PW group (Figure 1).

Maximal knee extension exercise

At analysis for maximal knee extension exercise, we divided into five frames of 100-repetition knee extension at the peak torque of isokinetic knee extension exercise [18]. Each frame was corresponded to 20 repetitions; Frame 1 for the first 20 repetitions, Frame 2 for the following 21-40 repetitions, Frame 3 for 41-60 repetitions, Frame 4 for 61-80 repetitions and Frame 5 for the last 81-100 repetitions. Although the peak torque of subjects treated with PW significantly decreased during the first 40 repetitions (Frame 1-2), the reduction of peak torque in the subjects given HW did not reach statistical

Table 2 Changes in Blood Levels

		0 min	45 min	60 min	90 min	120 min
d-ROMs (U.CARR)	PW	269.0 ± 50.8	285.7 ± 52.3*	287.0 ± 56.9*	274.2 ± 50.2	280.0 ± 47.6
	HW	281.3 ± 61.8	303.5 ± 46.3*	308.6 ± 56.1*	296.1 ± 57.9	307.0 ± 45.8
BAP (μmol/L)	PW	2347.3 ± 155.8	2648.9 ± 96.5*	2632.8 ± 146.4*	2349.6 ± 152.0	2321.8 ± 196.9
	HW	2336.7 ± 123.1	2659.1 ± 102.1*	2664.6 ± 201.0*	2299.8 ± 104.6	2356.4 ± 143.7
CK (IU/L)	PW	247.0 ± 105.1	296.5 ± 119.9*	300.9 ± 127.7*	264.7 ± 113.3*	256.3 ± 111.7
	HW	407.4 ± 269.9	483.2 ± 314.0*	478.1 ± 314.5*	428.2 ± 282.0	353.7 ± 264.6

Data were shown as mean ± standard deviation (SD). *$p < 0.05$ vs 0 min.

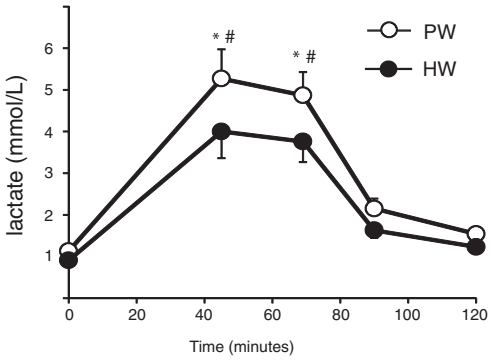

Figure 1 Sequential changes of blood lactate levels during exercise. Blood lactate levels in the athletes given PW significantly increased immediately after exercise compared to the levels at pre-exercise. HW significantly reduced blood lactate levels post exercise using bicycle ergometer. (*p < 0.05 vs. time 0. #p < 0.05 vs HW, N = 10).

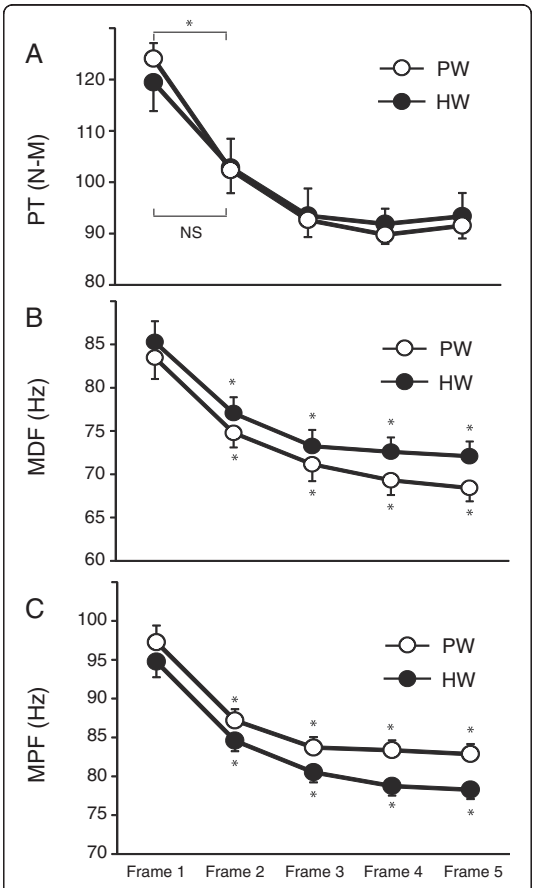

Figure 2 (A) Changes in peak torque (PT) every 20 repetitions (rep = 1 frame) during 100 maximum isokinetic knee extensions. PT of the subjects treated with PW significantly decreased during the initial 40-60 contractions by approximately 20-25 % of the initial values, followed by a phase with little change. On the other hand, there was no statistical difference between Frame 1 and Frame 2 in HW, indicating that HW prevented the decreasing the peak torque during the first 2 Frames. HW, Hydrogen rich water; PW, Placebo water. (*p < 0.05 vs Frame 1, N = 10). **(B) Changes in median frequency (MDF) every 20 repetitions (rep = 1 Frame) during 100 maximum isokinetic knee extensions.** Although exercise significantly reduced MDF values during the first 2 Frames, there was no statistical difference between HW and PW in all Frames. HW, Hydrogen rich water; PW, Placebo water. (*p < 0.05 vs Frame 1, N = 10). **(C) Changes in mean power frequency (MPF) every 20 repetitions (rep = 1 Frame) during 100 maximum isokinetic knee extensions.** There was no statistical difference between HW and PW in all Frames. HW, Hydrogen rich water; PW, Placebo water. (*p < 0.05 vs Frame 1, N = 10).

difference, suggesting that HW inhibited the early decrease of peak torque of the subjects (Figure 2 A).

MDF and MPF from EMG analysis

MDF and MPF in the subjects treated with PW or HW significantly decreased with time during exercise. While these values significantly decreased at Frame 1-2, there was no statistical difference between the subjects receiving PW and those receiving HW (Figure 2 B, C).

Discussion

In this preliminary study, we showed that hydration with HW attenuated increase of blood lactate levels and prevented post-exercise decrease of peak torque, an indicator of muscle fatigue. Muscle fatigue is caused by many different mechanisms, including the accumulation of metabolites within muscle fibers and the generation of an inadequate motor command in the motor cortex. The accumulations of potassium, lactate, and H^+ have often been suggested as being responsible for the decrease in muscle contractility [19]. In addition, aerobic, anaerobic, or mixed exercise causes enhanced ROS production, resulting in inflammation and cellular damage [20]. Short bursts of heavy exercise may induce oxidative stress through various pathways such as electron leakage within mitochondria, auto-oxidation of the catecholamine, NADPH activity, or ischemia/reperfusion [21]. Although the mechanism involved in the efficacies of HW remains unclear, our results show that hydration with HW could be feasible for acute exercise. Proper and adequate hydration is helpful for elite athletes to achieve the best performance. HW can easily replace regular drinking water on a routine basis and would potentially prevent adverse effects associated with heavy exercise.

Factors such as age, nutritional status, training level, and physical activity category can influence the results [22,23]. Although we had anticipated that hydrogen, a known antioxidant, would reduce oxidative stress following acute exercise, the effects of oral intake of HW were marginal and did not affect the level of oxidative markers after exercise. This can be explained by the facts that the athletes in our study have routinely trained and their antioxidant defense systems may be more active. Previous studies reported that repeated aerobic training increases antioxidant enzyme activity and subsequently decreases oxidative stress [2,24-26]. Also, considering the short life-span of hydrogen in circulation [27], more frequent drinking of HW during exercise might have additional effects. In a future study, the efficacy of HW on untrained subjects or recreational exercisers, who may have poorly established antioxidant systems to combat exercise-induced oxidative stress, should be tested. Furthermore, different drinking protocols should be investigated.

We quantified muscle fatigue as a decline in the maximal force or power capacity of muscle, which means that submaximal contractions can be sustained after the onset of muscle fatigue. Similarly, blood lactate concentration is one of the most often measured parameters during clinical exercise testing, as well as during performance testing of athletes. Lactate has often been considered one of the major causes of both fatigue during exercise and post-exercise muscle soreness. Lactate generated from the anaerobic breakdown of glycogen in the muscle occurs only during short bouts of relatively high intensity exercise and it is usually related to fatigue and muscle soreness. Previous evidence has shown that inorganic phosphate from creatine phosphate was the main cause of muscle fatigue [28].

Dehydration in athletes may also lead to fatigue, poor performance, decreased coordination, and muscle cramping. Although further investigations will be warranted, drinking HW may be an appropriate hydration strategy [29]. In this study, we administered HW or PW to subjects prior to exercise. Further investigation is required to determine the best timing, dose, and hydrogen concentration of drinking water to optimize the effects of HW.

In conclusion, our preliminary data demonstrated that consumption of HW reduced blood lactate levels and improved muscle fatigue after acute exercise. Although further studies are absolutely warranted, drinking HW would be a novel and effective fluid hydration strategy for athletes.

Competing interests
The authors declare that they have no competing interests.

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Author details
[1]Doctoral Program in Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Ibaraki, Japan. [2]Department of Emergency and Critical Care Medicine, Hyogo College of Medicine, 1-1, Mukogawa-cho, Nishinomiya, Hyogo 663-8501, Japan.

Authors' contributions
KA, TA and YM participated in the protocol design and the data accumulation. AN conceived the study and drafted the manuscript. SM participated in the study design and coordination. All authors read and approved the final manuscript.

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