

## FANTASTIC FINDINGS

# Hyperthermia Induces Venous Blood Alkalosis: A Study in Five Ironman Triathletes

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## ABSTRACT

To study the relationship between athletic performance in extreme heat and blood chemistry abnormalities, five Ironman triathletes were subjected to a hyperthermic chamber for one hour. The goal was to simulate the excessive heat and the feelings they experienced during their suboptimal athletic performances in the Ironman Triathlon. The hypothesis of the study was that accompanying the hyperthermia was extreme blood alkalosis and this, not dehydration or electrolyte abnormalities, was responsible for these five athletes' suboptimal performances during their various Ironman races.

One of the subjective feelings that the participants self-rated during this experiment was their perceived ability to run. This feeling of "ability to run" steadily decreased during their time in the hyperthermic chamber. As their core temperatures increased in the chamber, so did their venous serum blood pH levels, with all participants sustaining extreme degrees of venous blood alkalosis. It was this blood alkalosis that correlated closest to their feelings of an inability to run and other unpleasant feelings that they experienced during their recent Ironman Triathlon races.

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athletic performance also begins to decrease.<sup>1-4</sup> Fortney and Vroman, in their study on exercise performance and temperature control said, "...the effect of high ambient temperatures on exercise performance is most evident in prolonged submaximal exercise,"<sup>5</sup> as is the case in Ironman Triathlons. These researchers and others have primarily examined the effects of body core temperature in athletes and how it relates to decreased blood volume and dehydration, the shunting of core blood reserves to the athlete's peripheral surface and hypothalamic thermal regulation.

It has been concluded that optimal athletic performance, especially in endurance activities such as running and cycling, is achieved in moderate external temperatures.<sup>6,7</sup> A study featured in the *New York Times* showed that runners perform best in temperatures ranging from 41 to 50 degrees Fahrenheit.<sup>8</sup> Nielsen, et al, in their paper on heat acclimation, measured core temperatures in eight athletes during 90 minute exercise periods and their experiment showed that in a cool environment of 18-20 degrees Celsius (64.4 to 68 degrees Fahrenheit) core temperature remained steady at 37.8 degrees C (100 degrees Fahrenheit); but in a 40 degrees C (104 degrees F) environment core temperatures rose to nearly 40 degrees C (104 degrees F) during the exercise period, with a corresponding decrease in performance.<sup>9</sup> It has been documented that as external temperatures rise, so does an individual's body temperature.<sup>10-12</sup> Consequently, as exercise in high temperatures persist and basal body temperatures continue to rise, pace and performance begin to decrease.<sup>13, 14</sup> There is debate as to what physiological parameters in the blood cause levels to decrease in athletic performance with elevated temperature. Febbraio and Snow, in their study on the effect of heat stress on muscle energy metabolism during exercise, showed that sustained maximal voluntary muscle contraction with leg extensions attenuated in hyperthermic conditions.<sup>15</sup> Galloway and Maughan, in

## INTRODUCTION

**B**ody temperature regulation is an important component of any exercise or training regimen. This is especially true for the endurance athlete competing in a high temperature environment. If the ambient temperature becomes too high, the athlete reaches a point where elevated body temperature and dehydration ensue. As a result, symptoms such as cramping, nausea, dizziness, and weakness appear. At this time,

their paper on the effects of ambient temperature on the capacity to perform prolonged exercise, said that reduced performance at 31 degrees C (88 degrees F) would most likely result from a reduction in central blood volume.<sup>16</sup> This occurs as the body shunts blood peripherally for more efficient cooling. Several physiological parameters are affected by a rise in basal body temperature. Studies have examined various blood and urine test results and how they are affected by hyperthermia. Some have looked at how hyperthermia can result in a breakdown of electrolytes and can increase the use of muscle glycogen stores, likely resulting in decreased ability and increased fatigue.<sup>17-19</sup> Another study has shown hyperthermia to deplete intercellular glutathione content, thus possibly affecting immune response.<sup>20</sup> While the endurance athlete competing in high heat is at risk for dehydration, for the athlete not dehydrated, the etiological basis for a decline in the athlete's performance with hyperthermia is not known. The high external temperature fluctuations of the Ironman were simulated with the use of an infrared heating chamber in a controlled environment so that objective lab tests and subjective surveys could be administered to the participants.

**MATERIALS & METHODS**

This study examined how various biochemical parameters were affected in five Ironman triathletes subjected to hyperthermia via a hyperthermia chamber. The focus of this study was to look at several venous blood markers, including venous serum blood pH, osmolality and electrolytes, among others, to see which correlated best with the athletes' hyperthermia and survey questions, including "body aches" and "ability to run," among others.

**SUBJECTS**

The subjects were five athletes, four male and one female, who had completed an Ironman Triathlon in 2005. The race is comprised of a 2.4 mile swim, 112 mile bike, and a 26.2 mile run with a cut-off time of 17 hours to complete the course. The five participants in this study each raced in extreme heat and humidity in the summer of 2005, and had sub-optimal performances leading to an inability to run

during the marathon portion of the Ironman Triathlon. Each athlete had finishing times much higher than were anticipated because they had to walk an average 15-18 miles of the marathon because of being overheated. (See Table 1.)

The triathletes were asked to lay in a Far infrared (FIR) hyperthermia chamber within five months of completing their individual race event. The chamber was to simulate the conditions that caused them to stop running in the Ironman Triathlon. (See Figure 1.) Venous blood pH and electrolytes were measured every 15 minutes during the study and other variables at the beginning and the end of the study. The chamber used for the study was a BioTherm with 90+% Far infrared (FIR), 5-14 microns, peak 9.25-10.2 with an analogue controller.

The study design included a blood and urine test analysis of 17 different biochemical parameters and 13 self-reported survey questions pertaining to physical changes such as perceived temperature, mental clarity, nausea, energy level, and ability to run. The patients arrived at the clinic well-hydrated and having eaten a few hours prior to the study. Temperature, vital signs, blood tests, and survey questions were administered at the beginning and end of the 60 minute experiment, as well as every 15 minutes during the time that the participants spent in the chamber. Urine was only collected at the beginning and end of the trial, while blood was collected every 15 minutes via a venous catheter that remained in place.

The Nova machine used to test the venous serum pH and electrolytes was a Model 8 NOVA CRT machine designed by NOVA Biomedical Corporation. This laboratory machine at the primary author's office read normal venous serum pH as 7.50-7.52.\*

\*The NOVA 8 CRT machine used in 2005 to analyze the venous blood pH used serum where the normal venous serum blood values were 7.50 to 7.52. Currently, the primary author's lab now uses a NOVA Model CCX laboratory machine to analyze pH and it uses 7.36 to 7.38 as normal values, using whole venous blood instead of serum.

**Table 1. Demographics, race conditions, and athletes' projected vs. actual race times.**

Subject	Sex	Age	2005 Ironman Event	Weather Conditions	Projected Time	Actual Time
AP	M	37	Wisconsin	98° Fahrenheit (F) with 95% humidity	13 hours	14 hr 44 min
KH	F	27	Wisconsin	98° Fahrenheit (F) with 95% humidity	13 hours	14 hr 22 min
JC	M	44	Wisconsin	98° Fahrenheit (F) with 95% humidity	13 hours	14 hr 44 min
TK	M	37	Canada	87° Fahrenheit (F) with 85% humidity	11 hours	12 hr 42 min
RH	M	42	Canada	87° Fahrenheit (F) with 85% humidity	12 hours	13 hr 15 min



**Figure 1. One of the athletes in the hyperthermia chamber during the one hour study.**

Anti-oxidant assay (AOA) level started at 1.1, and ended at 1.3. Cortisol levels began at 12.7 and increased to 19.0 following exposure to the extreme heat. (See Table 2.)

**Table 2. Antioxidant and cortisol levels before and after hyperthermia.**

	Glut-rbc	Glut-plasma	AOA	Cortisol
<b>Average Before</b>	250	142.4	1.1	12.7
<b>Average After</b>	218.8	190.4	1.3	19.0

The blood samples were drawn into a marble-top tube (SST), allowed to coagulate for 30 minutes, then spun down in a centrifuge for 15 minutes. The serum was drawn off and immediately tested as the serum pH will change soon after being exposed to air.

Serum osmolality (Osmo) averaged 296.2 at the start of the study and rose to 302.2 at the end. The average white blood cell (WBC) count was 7.26 before and 8.08 after. Hemoglobin (HGB) began at 13.6 and ended at 15.9. Hematocrit (HCT) starting levels averaged 43.28 and finished at 46.72. Platelets (PLT) began at 278.4 and increased to 303.8. Urine specific gravity (UASG) began at 1.018 and ended at 1.0162. Urine pH (UAPH) started at an average of 6.4 and ended at 6.5. There was only a small change in C-reactive protein (CRP) as well; levels began at 0.62 and ended at 0.64. Finally, Ferritin (Fer) levels averaged 106 prior to the experiment and rose to 114 after. (See Table 3.)

The following biochemical variables were analyzed: venous blood pH, urine pH, glutathione rbc, glutathione plasma, anti-oxidant assay, (peroxidase, catalase and superoxide dismutase) cortisol, serum osmolality, urine specific gravity, white blood count, hemoglobin, hematocrit, platelets, ferritin, C-reactive protein, magnesium, potassium and calcium.

**Table 3. Blood and urine chemistries before and after hyperthermia.**

	Osmo	WBC	HGB	HCT	PLT	UASG	UAPH	CRP	Fer
<b>Average Before</b>	296.2	7.26	13.6	43.3	278.4	1.0	6.4	0.62	106
<b>Average After</b>	302.2	8.08	15.9	46.7	303.8	1.0	6.5	0.64	114

**RESULTS**

The five athletes consented to have their data collected for scientific research. As stated, four were men (80%) and one was a woman (20%). All were friends and training partners during their preparation to complete an Ironman event in 2005.

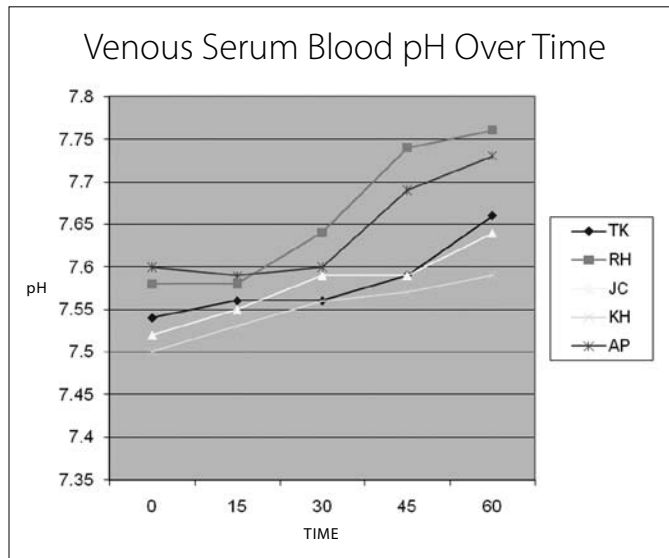
The average potassium level began at 4.35. After 30 minutes it dropped to 4.20, and ended at 4.36. Calcium panels began at an average of 4.83. Thirty minutes into the experiment it increased to 4.87, and ended at 5.01. Magnesium panels began at an average of 1.21. Midway levels were documented at 1.23, with an ending average of 1.31. Sodium levels began at an average of 141.0, after 30 minutes averaged 142.3, and ended at 143.8. (See Table 4.)

Averages for the different biochemical parameters were taken before and after each subject spent 60 minutes in the infrared heat chamber. The average starting glutathione red blood cells (glut-rbc) was 250, and the average ending 218.8. Glutathione plasma (Glut-plasma) began at an average of 142.4, and increased to 190.4. The average

**Table 4. Electrolyte levels before, during, and after hyperthermia.**

	Calcium	Magnesium	Potassium	Sodium
<b>Average Before</b>	4.83	1.21	4.35	141.0
<b>Average After 30 minutes</b>	4.87	1.23	4.20	142.3
<b>Average After 1 hour</b>	5.01	1.31	4.36	143.8

In terms of pH, normal levels range from 7.50-7.52 when samples are run on the Model 8 NOVA. *Figure 2* depicts the actual result for the five athletes. Note all participants experienced increases in all blood pH values as their time in the hyperthermia chamber increased. (See *Figure 2.*) The average venous serum blood pH for the five athletes began at 7.55, increased to 7.59 after 30 minutes, and ended at 7.67 after 60 minutes.

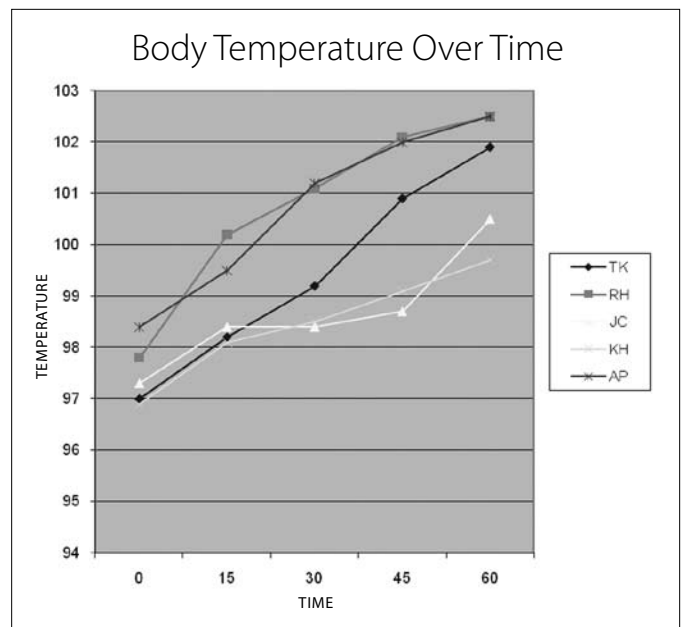


**Figure 2. Venous serum blood pH changes over time.** The venous serum blood pH of all five study participants became more alkaline as time in the hyperthermia chamber increased.

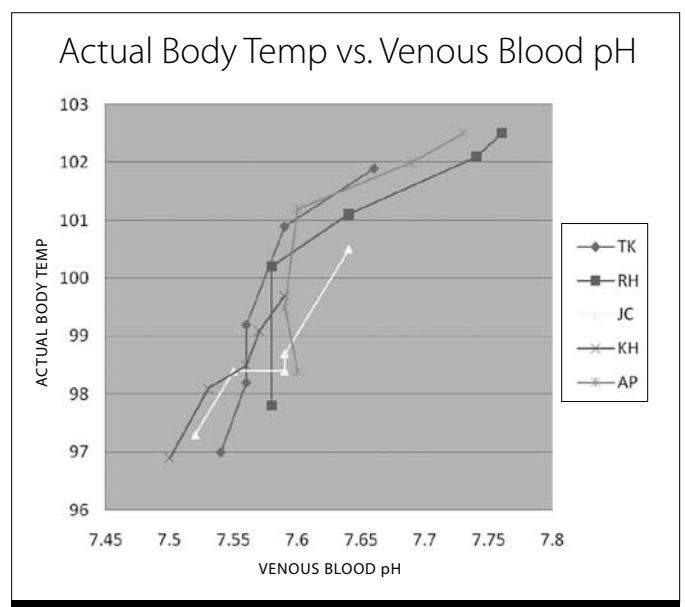
Normal core body temperature in humans is 98.6 degrees Fahrenheit. In this study, beginning body temperature averaged 97.5 degrees, and it rose to 99.7 degrees after 30 minutes in the heating chamber, and after 60 minutes was 101.4 degrees. (See *Figure 3.*)

When the actual body temperature of the five athletes was plotted against their changes in blood pH, it becomes even clearer that extreme body temperatures correlated with rises in venous serum blood pH. (See *Figure 4.*)

Subjects were asked to rate their answers to the survey questions at the beginning, as well as after every 15 minutes for the hour they were lying in the chamber. All question used an interval scale of 0 to 10. Ten indicated the most positive subjective response with 0 indicating the most negative. Not all of the reported responses began with a rating of 10 because if one subject did not feel “optimal” at the start of the experiment, the overall starting average for that variable would be less than 10. For example, the



**Figure 3. Body temperature changes over time.** Body temperatures rose in each of the five athletes when placed in the hyperthermia chamber for 60 minutes.



**Figure 4. Actual body temperature compared to venous blood pH in five athletes.** A direct correlation is seen in increased body temperature and alkalosis.

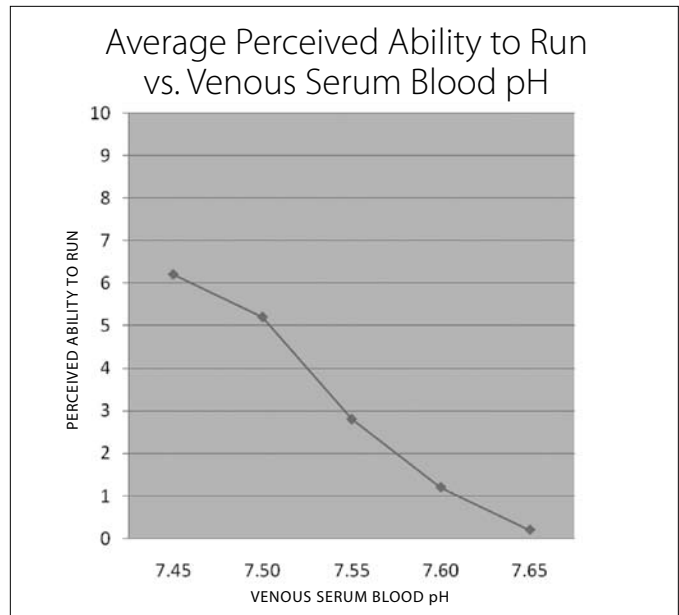
subjects were asked to rate their mental clarity during the experiment. At the beginning of the proceedings, the self-rated average mental clarity was 9.8. Halfway through the trial, the average mental clarity dropped to 7.6, and upon completion of an hour in the hyperthermia chamber, the subjects rated their average mental clarity as 3.2.

“Overall feeling” was a subjective ranking, best explained by the question and answer, “How do you feel? Answers: “Great, good, fair, or awful.” By assigning numeric rankings to this question, 10 was the average starting response, 7.2 the average at 30 minutes, and 5.6 at the end of the 60 minutes in the chamber. Averages answers to all of the survey questions can be seen in *Table 5*, including thirst, ability to breathe, amount of sweat, comfort/temperature perception, stomach feeling/ache, headache/head pressure, appetite, and body achiness.

**Table 5. Average answers to all of the survey questions.**  
(10= ideal/great/normal. 0= worst feeling/terrible).

Survey Questions	Starting Ranking	Halfway Ranking (after 30 minutes)	Ending Ranking (after 60 minutes)
Ability to breathe	10	8.0	7.4
Appetite	10	7.6	5.8
Body achiness	10	8.6	7.4
Comfort	10	6.2	1.8
Headache/pressure	10	8.6	7.2
Mental clarity	9.8	7.6	3.2
Nausea	10 (none)	8.4	5.4 (worsening)
Overall feeling	10	7.2	5.6
Perceived energy	9.8	7.6	3.2
Sweating	10 (not sweating)	5.2	4.2 (profuse)
Stomach feeling	10	8.4	5.4
Thirst	10	6.6	4.0

Lastly, the subjects were asked about their perceived ability to run at different intervals throughout the experiment. The athletes’ starting ability to run averaged 6.2. They did not start out with a higher average due to the participants having varying degrees of injuries, illness, and pretrial fatigue, which they perceived would affect their ability to run as compared to how they would run if at peak condition (peak condition being a 10 on the scale used in this study). A rating of three meant the athlete felt he or she would only be able to walk, and a rating of two meant the athlete felt he or she would only be able to walk very slowly. A rating of one meant barely able to walk at all, and a rating of 0 would be completely stopped. After 30 minutes, the average rated ability to run was 2.8, and at the end of the trial it had further decreased to 0.2. When the athletes’ perceived ability to run is plotted against venous serum blood pH, a direct negative correlation is seen. (See *Figure 5*.)



**Figure 5. Perceived ability to run versus venous serum blood pH.** As the blood pH rises a subsequent perceived inability to run is seen.

DISCUSSION

In this study of five triathletes, their experience in the hyperthermia chamber clearly replicated the overheated feeling, exhaustion, and nausea that occurred during their Ironman event. During the one hour study, serum osmolality levels did increase, as did electrolyte levels, but not to the degree to signify dehydration. Cortisol levels increased drastically, and large changes in glutathione levels were also observed, which confirmed that the high body core temperatures were causing significant distress to the participants. Venous blood alkalosis is the most likely blood parameter responsible for the unpleasant feelings associated with the hyperthermia. While there were some changes in the various blood biochemical parameters, the most notable changes were in venous serum blood pH. As time elapsed and core body temperature increased, the participants’ blood pH climbed from its initial average of 7.55 to 7.67 after one hour in the hyperthermia chamber.

Blood pH and its relationship to exercise have been studied by looking at opposite ends of the spectrum. Anaerobic exercise, short duration, high-intensity exercise, the type sprinters and power-lifters perform, for example, produces some level of metabolic acidosis in the athlete, due in part to the production of lactic acid in the muscles. Aerobic exercise, the type that triathletes and marathon runners

perform, causes the athlete to lose large amounts of sweat containing electrolytes, particularly chloride, leading to metabolic alkalosis. This anion, chloride, is lost in large amounts (salty taste of sweat) during long-duration aerobic exercise. Severe metabolic alkalosis is feared in pediatrics, especially in neonatal settings, because sweating in infants can lead to excessive chloride wasting,<sup>21</sup> whether due to high ambient temperatures or diseases like cystic fibrosis, where one symptom of CF is very salty sweat because of inordinate amounts of sodium chloride being lost through the skin.<sup>22</sup> Alkalosis is also monitored in the veterinary arena, especially in performance animals like horses. Prolonged slow work causes heavy sweat loss and pH rises, causing poor performance, nervousness, and muscle cramping.<sup>23</sup> Thus a thoroughbred horse sprinting in a short race would be at risk of acidosis, while a show horse in dressage would be subject to alkalosis.

Venous blood pH, which seemed to have the most influence on the subjects' performance, or their "ability to run," was measured because the body's enzymes work optimally within a narrow range of blood pH. These enzymes are the catalysts which speed up the reactions in the oxidative phosphorylation process by which the body produces energy in the mitochondria of the cells.<sup>24</sup> Basically all metabolic processes in the body are run by a series of enzymes, all of which function at an optimum pH. As with all enzymes, extremely high or low pH values can lead to a complete or partial loss of activity of a particular enzyme.<sup>25</sup> An animal study using frogs looked at the enzyme phosphofructokinase, involved in the one of the rate-limited steps during oxidative phosphorylation in reptilian and human metabolism. It was found that a small shift in pH caused this enzyme to lose its ability to function, thereby dramatically slowing down metabolism.<sup>26</sup> When pH fluctuates outside its very narrow optimal range, enzyme activity slows down. As enzyme activity slows, the body's ability to make energy is also slowed and energy reserves suffer.<sup>27</sup> Energy production and athletic performance go hand-in-hand. If energy production wanes for whatever reason, athletic performance will logically drop.

Anyone who has watched an Ironman Triathlon race on television, spectated one, or completed one knows that this is one of the toughest one-day endurance events in the world. Obviously an athlete's physiology during a 10 to 17 hour event like the Ironman will be severely challenged. As such, multiple parameters were evaluated

in this study. Endurance athletics cause drastic fluctuations in mineral and hydration levels. Mineral levels such as potassium, sodium, magnesium, and calcium were evaluated in this study. These changed very little in the five athletes we studied, so changes in mineral levels could not have accounted for the drastic changes in the athletes' demeanor and feelings in the hyperthermia chamber. To evaluate hydration levels, urine specific gravity and serum osmolality were checked. These both increased (along with hemoglobin and hematocrit), suggesting the athletes were starting to get water depleted but stayed within the normal range, thereby eliminating dehydration as the cause of these participants' symptoms subjected to hyperthermia. Urine pH was looked at because it can give insight as to whether or not a subject is experiencing metabolic or respiratory acidosis if the urine is too acidic. It may also give an indication of respiratory alkalosis due to hyperventilation if the urine is too alkaline.<sup>28</sup> As cellular respiration is increased dramatically during high-level athletics, urine pH was measured in this study. Urine pH generally stayed the same, even though the blood pH became very alkaline.

Additional cellular damage occurs with the increase of cellular respiration in endurance events, challenging the athletes' antioxidant reserves. Glutathione levels in the red blood cells and plasma were studied, along with the anti-oxidant assay, measuring the enzymes glutathione peroxidase, catalase, and superoxide dismutase. The anti-oxidant assay results before and after hyperthermia exposure were relatively unchanged, while glutathione levels were drastically affected. Glutathione in the red blood cells and plasma were measured because of the role of glutathione in preventing cellular damage caused by free radicals produced during cellular respiration.<sup>29, 30</sup> Glutathione is also involved in the detoxification of harmful compounds, in the formation and maintenance of disulfide bonds in proteins and in transport of amino acids across cell membranes.<sup>31</sup> The large change in glutathione levels, along with cortisol, the main stress hormone, give credence to the notion that the five athletes, truly were stressed and enduring excessive tissue damage in the hyperthermia chamber. As the Ironman Triathlon event is extremely stressful, hormones such as cortisol will be secreted. Cortisol is the predominant glucocorticoid in the body. It is an essential component of adaptation to severe stress. The action which supports this stress reaction is gluconeogenesis,<sup>32</sup> the synthesis of glucose from molecules that are not carbohydrates, such as amino

and fatty acids.<sup>33</sup> This is important in endurance events. Since muscle tissue is damaged and causes inflammation, C-reactive protein (CRP) was also checked. The CRP test is a sensitive and quantitative measurement used to detect low-grade inflammatory responses, evaluating the severity and course of an inflammatory process; it is an abnormal protein, virtually absent from the blood of healthy people,<sup>34</sup> or those not participating in some type of endurance event. In this study, the CRP values changed very little, which may be due to the fact that the athletes did not receive enough tissue damage to change this value.

Hyperthermia is, of course, related to a spectrum of heat illnesses, with the most severe being heat stroke. Severe heat stroke denatures proteins, destabilizes phospholipids and lipoproteins, liquefies membrane lipids, leading to cardiovascular collapse, multi-organ failure, and ultimately, death.<sup>35</sup> The level of heat illness experienced by the study participants, however, did not approach heatstroke status, either in competition, or in the infrared chamber. The ambient temperature in the races and the generated heat in the chamber were factors in the subjects' blood becoming alkaline, but we must not forget the heat generated by their bodies during an actual competition. Strenuous physical activity can increase heat production more than 10-fold to levels exceeding 1000kcal/h.<sup>36</sup> Skin is the major heat-dissipating organ. At high ambient temperatures, evaporation, through sweating, becomes the most effective means of heat loss. So while an athlete can avoid acute heatstroke through proper hydration before and during a race, and hopefully having an efficient eccrine system, the negative effects on performance from rising blood pH levels are something else for the athlete to consider.

In this study as temperature and pH increased, mental clarity decreased 20.2% after 30 minutes, and 60.6% after 60 minutes in the chamber. Nausea increased by 10.6% midway through the experiment, and ended with an overall deficit of 40.6%. Running ability decreased by 60% midway through, and by over 95% at the conclusion of the study. While the exact chemical cause of these symptoms can not be proved in this study involving five people, venous blood alkalosis is one factor to consider. Basic biology and chemistry notes that the farther away from "optimum pH" for a particular enzyme, the less efficient that enzyme will work,<sup>37</sup> which most likely will result in a suboptimal performance for the athlete involved in high-level competition.

Future studies testing venous blood alkalosis would necessitate a larger sample size and would ideally involve athletes before and after actual competition in the heat. An apparent application of these results would be the control of blood alkalosis to enhance athletic performance for the athlete competing in the heat.

## CONCLUSION

This pilot study has shown that venous serum blood alkalosis increases in five triathletes exposed to extreme heat. As core body temperature increased and blood pH became more alkaline, symptomatic factors influencing athletic performance including mental clarity, nausea, and running ability were negatively impacted. Therefore, one can infer that blood pH plays an important role in athletic performance and should be considered when undertaking training programs for endurance activities. Future studies are needed to see if measures can be taken to lower an athlete's blood pH prior to or during an event through diet and/or supplements to help ensure alkalinity does not rise to such an extent as to impact performance. ■

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