Jeff S. Volek, PhD, RD
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THE ART AND SCIENCE OF LOW CARBOHYDRATE PERFORMANCE

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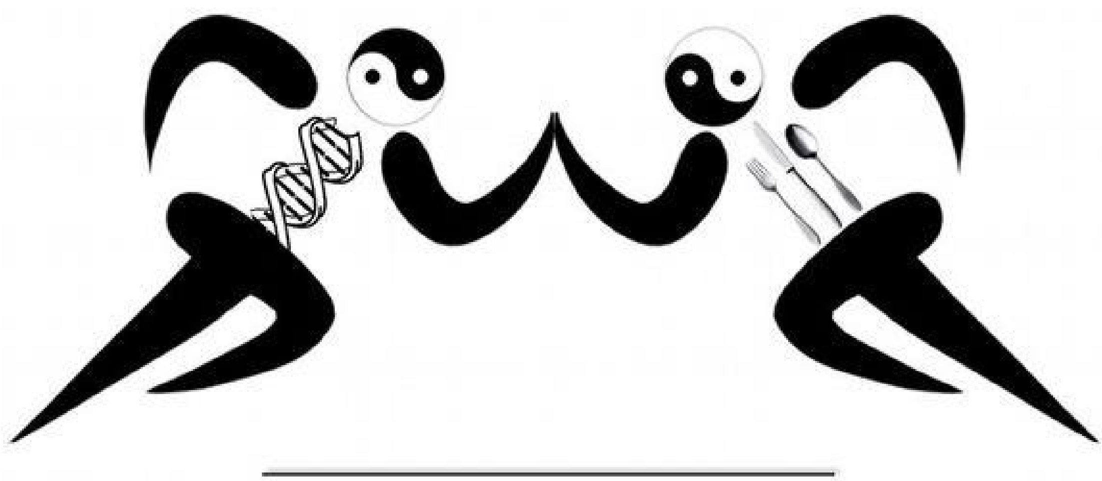

A Revolutionary Program to Extend Your Physical and Mental Performance Envelope

Jeff S. Volek, PhD, RD
Stephen D. Phinney, MD, PhD

Other Books by Jeff Volek and Steve Phinney

Men's Health TNT Diet
Jeff Volek and Adam Campbell
Rodale Books 2008

The New Atkins for a New You
Eric Westman, Jeff Volek, and Stephen Phinney
Fireside/Simon & Schuster 2010

The Art and Science of Low Carbohydrate Living
Jeff Volek and Stephen Phinney
Beyond Obesity LLC 2011
(available at www.createspace.com/3608659)

Above Evil – A Science Prediction Novel
Stephen Phinney
Beyond Obesity LLC 2012
(available at www.createspace.com/3779119)

The information in this book is provided to assist the reader in making informed choices about diet and exercise. This book is neither intended as a substitute for medical advice nor to replace professional athletic coaching. Before starting any diet, you should consult your personal physician.

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Contents

Acknowledgements

The opening paragraph of our recent book “The Art and Science of Low Carbohydrate Living discussed the ancient Chinese curse: ‘may you live in interesting times.’ In the intervening year, w sense even more movement towards a consensus change; whereby the clinical use of low carbohydra diets in the management of insulin resistance may soon become mainstream. We are genuinel appreciative of the positive and constructive feedback from people who have taken the time to wri us. Many of you asked specifically about exercising during a low carbohydrate diet, and several share your personal experience with us. Your feedback inspired us to write this book. Now we say to eac other “we live in ***really*** interesting times” because it’s looking like a consensus change on the use low carbohydrate diets for athletes may come sooner than their general use in medical care.

We are thankful for the support of the many people who encouraged us to address the role of lo carbohydrate diets in sports and exercise. We appreciate the thoughtful comments on early drafts fro Peter Defty, Peter Davis, Brian Kupchak, Brittanie Volk, and Cynthia Moore. A special thanks to tho low carbohydrate pioneer athletes who were willing to share their personal experience for this book Tony Ricci, Andrea Hudy, John Rutherford, Bettie Smith, Doug Berlin, David Dreyfuss, and Ja Wortman.

I (Steve Phinney) wish to thank Dr. Richard Handler who introduced me to cycling, Dr. Edwar Horton who got me started in performance research, and Dr. Bruce Bistrian who taught me to regar nutrition as a science. A special thanks to my co-author and friend Jeff, with whom writing is a joy and to Doug Bibus for his unwavering friendship and collaboration. Infinite appreciation goes to m family – to Lauren and Eric who put up with my abstruse verbal meanderings during road trips up ar down Interstate 5; and to my remarkable wife Huong, without whose intellectual GPS I would b forever lost on the backroads of detail.

I (Jeff Volek) wish to thank my supportive parents who provided me many opportunities to play ar compete in sports from a young age, Dr. Linc Gotchalk who coached me in the sport of powerliftin and Dr. William Kraemer who taught me a deep appreciation for the complexity of exercise science. special thanks to my co-author Steve, who has inspired and enriched my life beyond what I ca express in words. Above all I want to thank my loving and patient wife, Ana and my two boys, wh supported me in spite of the significant time this book project took away from them.

Section 1

Chapter 1

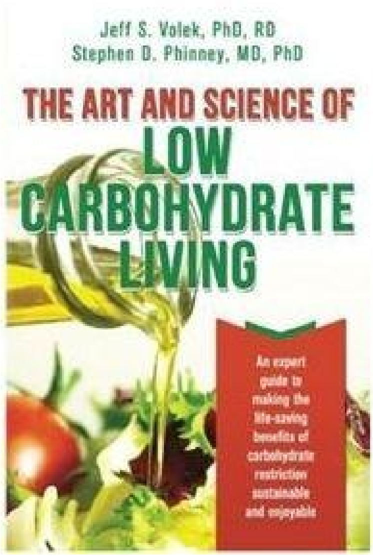
INTRODUCTION

Humans Can Fly

"Perfection is not attainable. But if we chase perfection, we can catch excellence."
-Vince Lombardi

If you are completely content with your body, health, and performance on a high carbohydrate di there is probably no reason to consider a low carbohydrate diet. If it isn't broke, don't fix it. But if yo have hit a plateau, are in a rut, suffer from overtraining, have trouble recovering from your workout want to change your body composition, or simply want to experiment with how your body adapts restricting carbohydrate, then this book is for ***"You"***.

"You" might be an elite athlete, coach, trainer, dietitian, physician or scientist. *You* might be a casu fitness enthusiast or wanna-be athlete. *You* might be new to exercise, a weekend warrior, or a vetera of the gym but aren't satisfied with your progress or feel drained. If any of these people are *You* th this book may have something valuable to offer.



In our recent book, 'The Art and Science of Low Carbohydrate Living'[1], we made a strong case f low carbohydrate diets as the preferred approach to managing insulin resistance (aka carbohydra intolerance). However, on the continuum of insulin resistance, athletes as a group cluster on the sid of insulin sensitivity. Thus most athletes do not have anywhere near the same level of carbohydra intolerance as someone who is overweight with metabolic syndrome or diabetes.

Why then would we recommend a low carbohydrate diet for athletes? After all, the current majori group-think in sports nutrition holds that all athletes have an obligate need for carbohydrate. B despite having the best intentions, the majority view does not always represent the truth. Besid exacerbating insulin resistance, ***a high carbohydrate diet also locks a person into a dependence o carbohydrate as the dominant fuel for exercise***. And every endurance athlete knows what happens t performance when their carbohydrate tank (at best holding 2000 Calories) runs dry – performanc goes down in flames. It’s an unfortunate reality that the human body is unable to promptly switc from carbs to fat as its predominant exercise fuel, so once the former is gone, you can’t power yo performance with fat (even though a carbohydrate-depleted body still has tens of thousands of f Calories on hand).

The key fact underlying this book is that you can train your body to burn fat by simply changing yo diet over a period of a few weeks, thereby turning blood sugar and glycogen into secondary fuel Once you make this transition, you can then train harder, perform longer, and recover faster. So th simple answer to why we endorse a low carbohydrate lifestyle for athletes is that this strategy h worked for us and many people we know. More importantly, we have both conducted and publishe human research that supports this approach, adding to a growing body of literature that now points the merits of reducing dietary carbohydrates to optimize fat metabolism. We have thus accumulated unique knowledge base that we want to share so you too may experience it for yourself.

.....

Do we understand that exercising without carbs is heresy? Absolutely, but think about it from th perspective. Before December 17, 1903, about 99% of the population thought that humans could nev fly. Not long after that, the proportions for and against the possibility of human flight were reverse In the 6000 years since small pockets of humanity first developed agricultural carbohydrates, most us have come to believe that agricultural carbohydrates are necessary for health, and particularly f sports performance. Is this indeed true? Or is it more akin to the world view on the day before th Wright Brothers flew? Perhaps most of us are victims of Stockholm Syndrome, having emotional adopted the distorted views of the agricultural paradigm that has us ensnared, if not enslaved.

Among scientists, and in the general population as well, some argue that dietary carbohydrates a addicting. Whether the human brain’s response to carbohydrate withdrawal is characteristic of a tru addiction response remains a topic of debate. However it is true that, from a functional perspectiv once you light your metabolic fire with carbohydrates, it is hard to ignore the incessant signals to kee feeding it more and more carbohydrates at frequent intervals.

Another aspect of our cultural dependence on carbohydrates stems from the low cost and high per-ac production that dietary carbohydrates deliver, allowing humanity to burgeon way beyond thos population levels supported by traditional hunting and herding cultures.

What is ‘best for a population’, however, may not be best for the individual. Elite athletes are, b definition, about as different from the general population as you can get. By whatever combination inborn capabilities plus intense training and commitment, athletes transcend the population’s norm both in physical performance and in nutrient needs. From this perspective, the correct combination foods which best make and sustain athletic prowess must be considered as potentially unique rath than ‘normal’.

Jared Diamond, the acclaimed geographer and author, notes that with the advent of agriculture Southern Europe, the average height of the population decreased by six inches, and the averag longevity declined by 10 years[2]. Similar effects were observed in Native North Americans whe agriculture was adopted a thousand years before Columbus discovered they were there. Holdou ~~against this agricultural trend, such as those nomadic cultures (e.g., Osage, Kiowa, Blackfee~~ Shoshone, Assiniboine, and Lakota) that lived almost solely on the buffalo, were 6-12 inches tall than the European settlers whose sustenance depended on wheat and corn[3]. Interestingly, the Mas in East Africa also lived as nomadic herders on a diet of meat and milk, and they too were known f their unusual height and physical prowess.

These observations support the concept that a diet consisting mostly of fat and protein can suppo remarkable growth, physical well-being and function – in essence, promoting the capabilities of t individual over commonly assumed societal norms.

But all of this information is old. Why write this booklet now? What has changed is that we (not ju the two of us, but the greater ‘we’ encompassing many colleagues) are now wrapping up a remarkab decade of human research on diets lower in carbohydrate and commensurately higher in fats a protein. In the last 10 years, ‘we’ have discovered that:

- Low carbohydrate diets are anti-inflammatory, producing less oxidative stress during exerci and more rapid recovery between exercise sessions.
- Physiological adaptation to low carbohydrate living allows much greater reliance on body fat, n just at rest but also during exercise, meaning much less dependence on muscle glycogen and le need to reload with carbohydrates during and after exercise.
- Low carbohydrate adaptation accelerates the body’s use of saturated fats for fuel, allowing a hig intake of total fats (including saturates) without risk.
- At the practical level, effective training for both endurance and strength/power sports can be do by individuals adapted to carbohydrate restricted diets, with desirable changes in bo composition and power-to-weight ratios.

A low carbohydrate lifestyle is not necessarily ideal for every athlete, but it is clearly desirable f some. To make an informed choice, however, every individual needs a basic understanding of how lo carbohydrate diets function to support human physiology. Much of this information has been cover in our recently published book “The Art and Science of Low Carbohydrate Living”. In additio however, both the athlete and coach/trainer need to understand how to integrate this diet with traini to yield superior performance, and how one can then sustain this functional peak to span a high volume of training and competition.

The purpose of this booklet is to provide this additional information to satisfy the specific needs individual athletes, whether your intent is competition or recreation. This goal is efficiently met providing you with 12 concise chapters with a minimum of theory and a maximum of practic direction. After considering this information and making appropriate changes in your diet, perha you too will experience a paradigm shift in how you feel and function, and maybe ‘catch excellence Humans can fly!

Procedural Note: We use a lot of acronyms in this book. While they are all defined when use initially, they tend to become an ‘alphabet salad’ in later chapters. To alleviate that problem, we ha provided a glossary of terms at the end of the print version of the book.

Chapter 2

METABOLISM BASICS

A Functional Look At Fuel Use

“We cannot solve problems by using the same kind of thinking we used when we created them.’
-Albert Einstein

Snap Shot

- Body stores of fat fuel (typically >40, 000 Calories [kcal]) vastly exceed its maximum stores carbohydrate fuel (~2,000 kcal).
- Fueling tactics that emphasize carbohydrate-based diets and sugar-based supplements bias yo metabolism towards carbohydrate while simultaneously inhibiting fat mobilization ar utilization.
- This suppression of fat oxidation lasts for days after carbohydrates are consumed, not just the fe hours following their digestion when insulin levels are high.
- This high carbohydrate paradigm produces unreliable results, especially during prolonge exercise when body carbohydrate stores are exhausted.
- In order to sustain a high level of performance under conditions of glycogen depletion ar decreased glucose availability, cells must adapt to using fat fuels. This process is referred to keto-adaptation which has the potential to improve human performance and recovery.
- Previously held beliefs about the magnitude of peak fat burning need to be reconsidered in th context of data obtained after keto-adaptation.

It is accepted dogma within the science of sports nutrition that carbohydrates are essential and th they are the preferred fuel for athletes. Indeed, over the last 45 years a great deal of progress has bee made in understanding how to use carbohydrates to optimize the metabolic response to physic activity. This understanding in turn has driven development of nutritional approaches to preve fatigue and improve exercise tolerance. We don’t want to play down the extraordinary work researchers who have contributed to this knowledge. However it is instructive to point out that ev since the observation over four decades ago that low muscle glycogen was associated with fatigu most of that progress has been focused on ways to enhance glycogen levels and carbohydra oxidation (e.g., carbohydrate loading, use of multiple sources of sugars, etc.). Little effort has bee devoted to developing methods to decrease the body’s dependence on carbohydrate during physic activity. The result is a billion dollar sports beverage and supplement industry that aggressive promotes rapidly absorbed sources of carbohydrate before, during, and after exercise. We contend th there’s a limit to what can be achieved by consuming sugary drinks and gels in hopes of deliverin optimized fuel flow, and that it is time to take a serious look at the other side of the coin.

Is the research used to support high carbohydrate diets flawed or in some way misaligned with wh we know about human physiology? Not exactly – it’s more a case of willful neglect. The belief th carbohydrate is the ideal fuel source and that a high carbohydrate diet is optimal for all athletes a self-reinforcing concepts that have been passed down to at least a couple generations of spo scientists. ~~Many of the experiments conducted during that time were designed in a specific mann~~ and data interpreted within a narrow mindset to support and confirm the high carbohydrate paradig The result is a classic example of conformation bias – the tendency to favor information that confirm a preconception or hypothesis regardless of whether it is true.

Despite the tenacity with which mainstream sports nutritionists defend the notion that a hig carbohydrate intake is an ***obligate*** component of all athletes' diets, a more accurate paradigm is th carbohydrates are an obligate part of your diet only as long as you keep consuming lots of them. If yo take a few weeks to break this self-perpetuating cycle, however, carbs can be reduced to an ***option*** nutrient for athletes. To appreciate this alternative view, it is helpful to understand the metabolic bas of the human fuel supply.

Fueling Exercise

Adenosine tri-phosphate (ATP) is the chemical energy that fuels body processes including musc contraction. It's literally the energy that causes your muscle fibers to contract and produce force. A rest we are constantly breaking down and synthesizing ATP. When you exercise vigorously, ATI demands increase several-fold. Since we can't store (nor do we eat) ATP in appreciable amount exercise causes an immediate need to rapidly make ATP from other energy sources. The two primar fuels our bodies draw on to do this are carbohydrate and fat. How the body chooses the proportion carbohydrate and fat to use for fuel is complex, but one factor that has a consistent and profour effect is the availability of carbohydrate. The more carbs that are available, the more carbs the boo burns; while at the same time shutting down access to its much larger fuel reserve – fat.

Carbohydrate Fuel Tank

As noted above, carbohydrate is often viewed as the preferred fuel for athletes. From a function perspective, this is curious because carbohydrates cannot be stored in large amounts in the bod When we talk about storing and burning carbohydrate, the 'common energy currency' used by th body is glucose. Glucose can be metabolized directly to make ATP, and glucose can also be stored i modest amounts as glycogen in skeletal muscle, and to a lesser extent in liver. On average, th maximum glycogen store you can accumulate is between 400-500 grams. And since 1 gram carbohydrate equals 4 kcal, you max out at about 1600-2000 kcal in your carbohydrate fuel tank. Eac gram of glycogen is also stored with a couple grams of water. If you carry more muscle mass, are we trained, and eat a high carbohydrate diet, your glycogen stores might be increased by up to anoth 50% or so, but the total amount of carbohydrate available in the body is still relatively low compar to available fat stores.

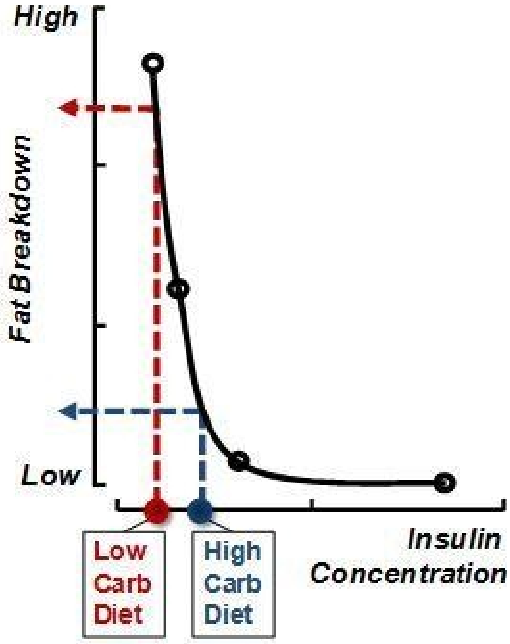
Fat Fuel Tank

Fat, or more specifically fatty acids, are stored in the body as triglycerides consisting of three fat acids linked to a single 3-carbon glycerol. Triglycerides coalesce into fat droplets that occupy ~85 of adipose tissue cells (i.e., fat cells, aka ‘adipocytes’). Unlike our limited storage of glycogen, f cells have a vast capacity to store fat. Since fat contains 9 kcal per gram and is stored with minim water, they are an efficient storage form of energy that can be mobilized quickly when blood insul levels are low. Even in a very lean athlete, the total amount of energy stored as fat will typically b more than 20 times the maximum level of carbohydrate stored in the body. Thus, whereas vigorou exercise can deplete glycogen reserves in just a few **hours**, when adapted to burning primarily fat, th thin athlete has enough fat to fuel several **days** of exercise.

During prolonged exercise when body stores of carbohydrate as glycogen are depleted, there increasing dependence on the liver to maintain blood glucose levels. This is not just to provide th exercising muscles with glucose, but also to support other normal body functions, especially th central nervous system. Decreased carbohydrate availability, particularly for the brain, marks th central event resulting in a sharp decline in physical and mental performance (i.e., *hitting the wall* *bonking*). The current practice of carbohydrate loading increases glycogen stores and is ofte accompanied by ingestion of sugar-based sport drinks and gels during exercise. These carb-base fueling tactics may delay the onset of hitting the wall, but for most athletes extending beyon marathon-duration events, they will still crash and burn despite having literally many thousan Calories worth of fuel tucked away in their fat cells. Why can’t this surplus of fat fuel be utilized eve at a time when the body desperately needs it? Simply put, it can be accessed, but it takes a few wee of carbohydrate restriction during which time the body becomes significantly more efficient burning fat, a process we call keto-adaptation (discussed in the next chapter).

Keto-adaptation allows rapid mobilization and utilization of “non-carbohydrate” lipid fuel sources. A the name implies, this process involves the conversion of fat to ketones in the liver, and these keton help supply the brain with energy when glucose levels fall. This affords even a very lean (10% bod fat) athlete access to more than 40,000 kcal from body fat, rather than starting a prolonged eve depending primarily on ~2000 kcal of glycogen.

How You Burn Body Fat: Fat Breakdown



Let's take a closer look at how we tap into the fat energy stored in adipose tissue. A key step i removing the fatty acid from the glycerol backbone (aka, fat breakdown or lipolysis). This is achieve by the enzyme hormone-sensitive lipase. Although many factors *stimulate* the activity of hormon sensitive lipase (e.g., epinephrine, norepinephrine, growth hormone, activated thyroid hormone), f breakdown is principally controlled by the single hormone that *inhibits* its activity. That hormone insulin. In other words, insulin is the primary gate-keeper of body fat. If your insulin levels a consistently high, fat usage is effectively blocked.

The primary nutrient that stimulates insulin is dietary carbohydrate. Some forms of carbohydra stimulate insulin more than others. Thus, consumption of insulin-stimulating carbohydrates is surefire way to inhibit your access to the energy stored as body fat during and after exercise.

Taking a closer look, the relationship between insulin levels and fat breakdown is not a straight lin Instead it's a steep curve, which means that fat release plummets with just a modest rise in insul such as those stimulated by most sports beverages. Looking at it from another perspective, near th bottom on the blood insulin range, just small decreases in insulin translate into large increases in f breakdown and fat oxidation[4]. Thus, focusing on keeping insulin low is associated with significa changes in fat metabolism, favoring decreased storage and increased fat oxidation. In case you' wondering, insulin's effect on fat breakdown does not take days or even hours, its effect is virtual immediate. Keto-adaptation, however, is not immediate. Keeping insulin low is a first step i increasing fat availability, but to maximize fat burning the body requires at least a couple weeks o uninterrupted low insulin levels (i.e., 2-3 weeks of consistently restricting dietary carbohydrates).

Factoid: *Like many things in life, a little bit of insulin is necessary, but more isn't necessarily bette Insulin's effects are not limited to promoting glucose uptake and suppressing fat breakdown. I addition to promoting storage of fat, insulin also potently and rapidly inhibits both blood fatty ac and total body lipid oxidation as well.*

How You Burn Body Fat: Fat Oxidation (Burning)

Breakdown of fat (aka lipolysis) in adipose tissue and its release into the blood is only half the stor Fatty ~~acids then need to be delivered to tissues like active muscle. Triglycerides and fatty acids~~ are n water soluble, so in the blood, fatty acids released from fat cells are attached to a protein calle albumin and delivered to muscle. Fat is taken up into muscle cells through specific transport protei and delivered to ATP-generating organelles within the cell called mitochondria. Transport of fatt acids into the mitochondria is highly regulated, and some might argue that this is the rate limiting st in oxidizing fat. The other fate for fatty acids taken up by muscle, particularly during periods of res is conversion back to triglyceride within the muscle cell itself where it is stored as lipid droplets f later use.

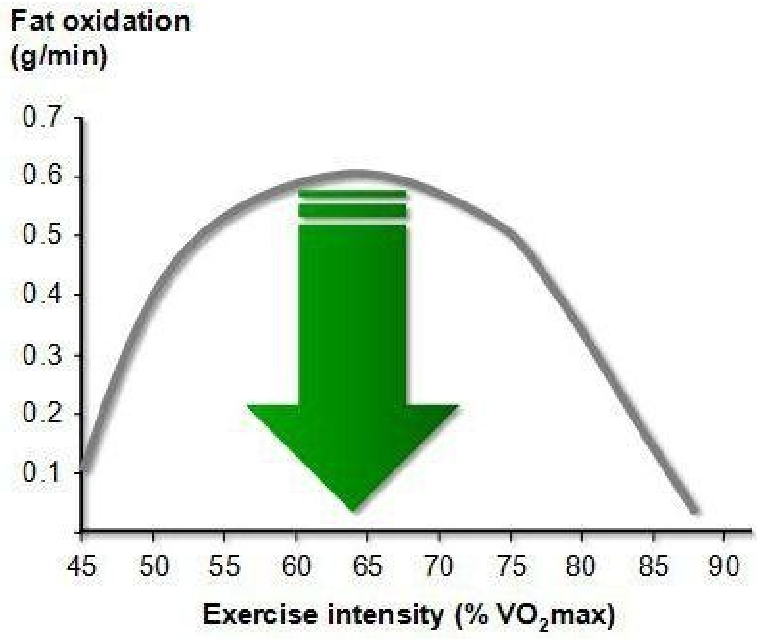
Factoid: *In the well-trained athlete, muscles cells can store as much energy in fat droplets as they ca store as glycogen.*

There you have it, the path of a fatty acid molecule from storage in fat cells to oxidation in muscl But where does dietary fat fit in? Dietary fat is absorbed from your small intestine and packaged triglycerides into a blood-bourne particle called a chylomicron. These are acted upon by fatty aci releasing enzymes called lipoprotein lipase that reside in the capillaries that perfuse muscle and f cells. The fatty acids released from chylomicrons can then be taken up by nearby muscle or fat cell Once inside muscle cells, the food-derived fatty acids mix in with the fatty acids delivered from f cells.

Exercise Intensity and Peak Fat Oxidation

One factor that impacts the proportion of fat used as fuel is exercise intensity. In athletes consumi moderate to high carbohydrate diets, as exercise intensity increases, the proportion of energy deriv from carbohydrate increases and that from fat decreases. This has been interpreted to mean that the is a specific exercise intensity where fat burning peaks, above which exercise at higher intensiti increasingly depends on glucose and glycogen.

If you start exercising lightly and gradually increase the intensity while simultaneously measuring t contribution of fat and carbohydrate to energy use, you will find that the peak rate of fat burni (grams of fat oxidized per minute or per hour) occurs *on average* at about 50% of maximal oxyg consumption (VO_2max) if you're untrained and at 65% VO_2max if you're trained[5]. Exercise hard and although power output increases, the contribution of fat decreases, forcing carbohydrate become the predominant fuel source. 65% of VO_2max is an intensity most endurance athletes c easily maintain for several hours. This means that if you exercise above this threshold, fat oxidati normally cannot increase to meet the greater energy demands. In fact, as you push up close maximal oxygen capacity, there is a rather sharp decline in fat oxidation – not just its proportion, b in absolute grams per minute as well. This is an important detail that requires greater inspecti because this line of reasoning is often used as justification to teach away from low carbohydrate/hig fat diets for athletes who exercise at or above 65% VO_2max.



Typical fat oxidation rates as a function of increasing exercise intensity.

First, several well conducted studies over the last few decades have provided multiple clues as to wh fat oxidation tends to decrease and carbohydrate becomes the predominant fuel at higher exerci intensities. It's not a simple switch that slows down fat oxidation as exercise intensity increases b rather a coordinated set of metabolic events. This metabolic symphony can play a different tune in keto-adapted athlete, allowing significantly higher rates of peak fat oxidation at higher exerci intensities. However the minimum time for this adaptation to occur has received little attention. Mo of the work in this area has involved athletes consuming low carbohydrate diets for less than tw weeks. In contrast, we have published studies of 4-6 weeks duration that demonstrate a progressive increased capacity to mobilize and oxidize fat[6, 7] at the 65% threshold. Thus the time allotted f adaptation has the potential to dramatically alter the 'typical' relation between exercise intensity ar fuel use.

Second, and more importantly, there is a great deal of variability between individuals consumin moderate to high carbohydrate diets (both trained and untrained) in their capacity to burn fat at re and during exercise[8]. Studies almost always highlight average responses for a group, but given suc variability between individuals, hardly anyone responds like the group average. Thus, when dealin with individuals, it's more interesting to look at the tails of the distribution (i.e., the outliers at th high and low ends of a group). For example, in a study of 300 people, peak fat oxidation range between 10 and 60 grams of total fat burned per hour. For some people peak fat oxidation occurred very low exercise intensities (e.g., 25% of VO_2max) whereas in others it occurred up to 77% VO_2max[9].

Factoid: *There are remarkable differences among individuals in both the magnitude of peak fa burning and the intensity of the exercise at which peak fat oxidation occurs.*

How Much Fat Can Humans Burn?

An intriguing question is whether oxidizing 60 grams fat per hour (1 gram per minute, or 540 kcal fat burned per hour) represents an absolute ceiling, or whether humans have the capacity to excee this level? The answer, it turns out, has been hiding in plain sight for almost 30 years. Not only ca this 60 gram per hour ‘butter ceiling’ be cracked, it can be totally splattered. Turn to the next chapte for ~~the key to unleashing your maximal fat burning potential. The reward for many readers~~ will b improved endurance performance as well as better control over your body composition (as in no lo of power with less total body fat).

Side Bar - Super Fat Burning Athletes

One way to explore the upper limits of fat oxidation is to look at “Super Fat-Burners” – athletes th show accelerated fat burning and, as a result, extraordinary endurance capacity. Yes, these ar animals; and yes, there are limits to their direct relevance vis-a-vis human exercise metabolis because of inherent species differences. But if nothing else, they do provide evidence for what possible in the context of mammalian physiology. It’s also interesting that these super animal athlete are characterized by an extraordinary ability to metabolize fat, not carbohydrate.

Genetically Modified Mice. These athletes have been referred to as “Mighty Mice” or “Super Mic owing to their ability to perform prodigious amounts of exercise[10]. Dr. Richard Hanson and h laboratory group at Case Western Reserve University made this serendipitous discovery durin experiments initially aimed at elucidating the role of PEPCK (phosphoenolpyruvate carboxykinase), key enzyme involved in the pathway that converts non-carbohydrate substances into glucose. The created a line of mice that over-produce PEPCK specifically in skeletal muscle.

What they discovered can be described as nothing short of astonishing. These mice were easi distinguished from normal mice because they were noticeably more active, ate more food, but we nonetheless leaner. They were up to 10 times more active, sometimes exercising continuously for u to 6 hours. This incredible propensity to exercise was accompanied by a remarkable capacity to bu fat despite having less subcutaneous and visceral fat stores. These mice had high levels of store triglycerides in their muscles and proportionately more mitochondria to burn that fat. Consistent wi accelerated fat burning, these animals also showed little accumulation of lactate during exerci compared to control mice, indicating much less reliance on muscle glycogen and glucose for fuel. D Hanson’s observations raise the question: could there be humans with increased muscle PEPCK, o could enzyme levels be increased through a change in diet?

Hunch: *Keto-adaptation in humans often results in a greater desire/drive to be physically activ likely because there is better total body fuel flow based on fatty acids and ketones. Could this b linked to increased muscle PEPCK. Any eager graduate students looking for a dissertation?*

Racing Sled Dogs. Equally impressive are dogs that compete in 1000 mile races like the Iditaro Successful dogs show an unusual fatigue-resistance that develops over the course of the event th spans 8-10 days. These unique athletes are able to pull their sleds more than 100 miles per day f consecutive days in environmentally harsh conditions. The best dogs transform their metabolism in way that avoids depletion of energy substrates and allows for rapid recovery. They actually replenis muscle glycogen over the course of consecutive days of strenuous exercise. Clearly they develop profound ability to utilize lipid fuel such as muscle triglycerides (which shows a progressive depletio over several days of exercise) as well as circulating fatty acids and ketones. Dogs are also known have higher albumin which gives them the capability of transporting more fatty acids in the blood, b

the full details of racing sled dog's metabolic dominance remains to be elucidated. What we do kno
is that the dogs perform and recover better on a diet that is high in fat, moderate in protein and low
carbohydrate content[11, 12].

Chapter 3

A TECTONIC SHIFT IN THINKING

Keto-Adaptation: The Most Efficient Path To Accelerated Fat Burning

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Snap Shot

- Ketones are an important lipid-based fuel source, especially for the brain, when dieta carbohydrates are restricted.
- The process of keto-adaptation (switching over to using primarily fatty acids and ketones) car be done 'on the fly' – it takes at least 2 weeks of preparation for this strategy to work.
- Keto-adapted athletes show marked increases in fat burning, indicating that peak rates of huma fat oxidation have been significantly underestimated.
- Keto-adapted individuals can do resistance training, and show profound improvements in boo composition.

Over the last four decades, carbohydrate-rich diets have been vigorously promoted to athletes base on the rationale that high carbohydrate oxidation rates are preferable to high fat oxidation rates, ar therefore maintaining a high muscle glycogen level is essential to achieve optimal performance. A you might guess by now, we've just got to say, "wait a minute!" Over these same four decades, we'v seen enough foot prints in the sand to lead us to the exact opposite conclusion – that a hig carbohydrate diet may be neither required nor desired for many athletes. Some might characterize th as a tectonic shift in sports nutrition thinking. We just consider this to be sound reasoning and part c the scientific process.

Why Low Carbohydrate Diets Remain a Fringe Concept

If we limit our scientific aperture to short-term studies comparing low-and high-carbohydrate die using brief periods of intense exercise, one could credibly argue the superiority of a high carbohydra diet. Today, however, a combination of time-tested experience and recent research data supports th conclusion that if humans are given two or more weeks to adapt to a well-formulated lo carbohydrate diet, they can deliver equal or better endurance performance compared to the best hig carbohydrate diet strategy. Combine this with the observational evidence of ultra-endurance athlete performing at consistently high levels using varying degrees of carbohydrate restriction to optimiz fat burning, and we have to believe it is time to reconsider the optimum diet for many athletes.

Despite having made significant progress in understanding how to optimize fat oxidation in athlete the ~~benefits of keto-adaptation on exercise performance and recovery have yet to be fully explo~~red humans. There have been a number of nutritional strategies aimed at increasing fat burning durin exercise such as caffeine, carnitine, ephedra, medium chain triglycerides, green tea extract, an hydroxycitric acid to name a few. Use of these supplements may mildly elevate fat burning; howeve they pale in comparison to the dramatic shift that occurs after a couple of weeks of adaptation to well formulated very low carbohydrate diet.

Keying In on Ketones

It's important to make a good first impression, but that was not the case with ketones. These organ acids were first discovered in urine of uncontrolled diabetic patients in the latter half of the 1 century. Although a much different picture has slowly emerged over the last 100 years, elucidating a important role for ketones in human health, the negative connotation associated with their debut h been hard to shake. This is both ironic and unfortunate because dietary strategies to increase keto production are now linked to improvements in several medical conditions, and perhaps spo performance as well. Yet there remains significant resistance to the rehabilitation of ketogenic diet and especially their use in athletes. As one prominent scientist put it "Ketones have bee Metabolism's 'Ugly Duckling'". However, thanks to ground-breaking studies on ketone metabolism they are now "emerging as an incipient swan."[13]

When we say ketones we are referring to two 4-carbon molecules – beta-hydroxybutyrate (BOHB) an acetoacetate (AcAc). BOHB and AcAc are made in the liver from fatty acids, and chemically the retain some similarities to the fatty acids from whence they come. However, being much small molecules, they are water soluble, making them easier to transport in the blood (more like the simp sugars whose functions they in part replace). Even when we eat a lot of carbohydrates, ketones a naturally present in our blood at relatively low levels, but their production increases in response decreased carbohydrate availability and accelerated rates of fatty acid delivery to the liver. This perfectly natural and in fact represents a vital adaptation in fuel partitioning when carbohydrate intak is low or carbohydrate reserves are depleted (e.g., at the end of a marathon).

Factoid: *The concept of keto-adaptation – that the human body requires a few weeks to adapt eating a low carbohydrate diet – was first voiced by a US Army surgeon and Arctic explorer, L Frederick Schwatka, in the early 1880s. This historical cornerstone, lost for a century, was reference by Dr. Phinney in his watershed 1983 study of bicycle racers adapted to an Inuit diet*[6, 14].

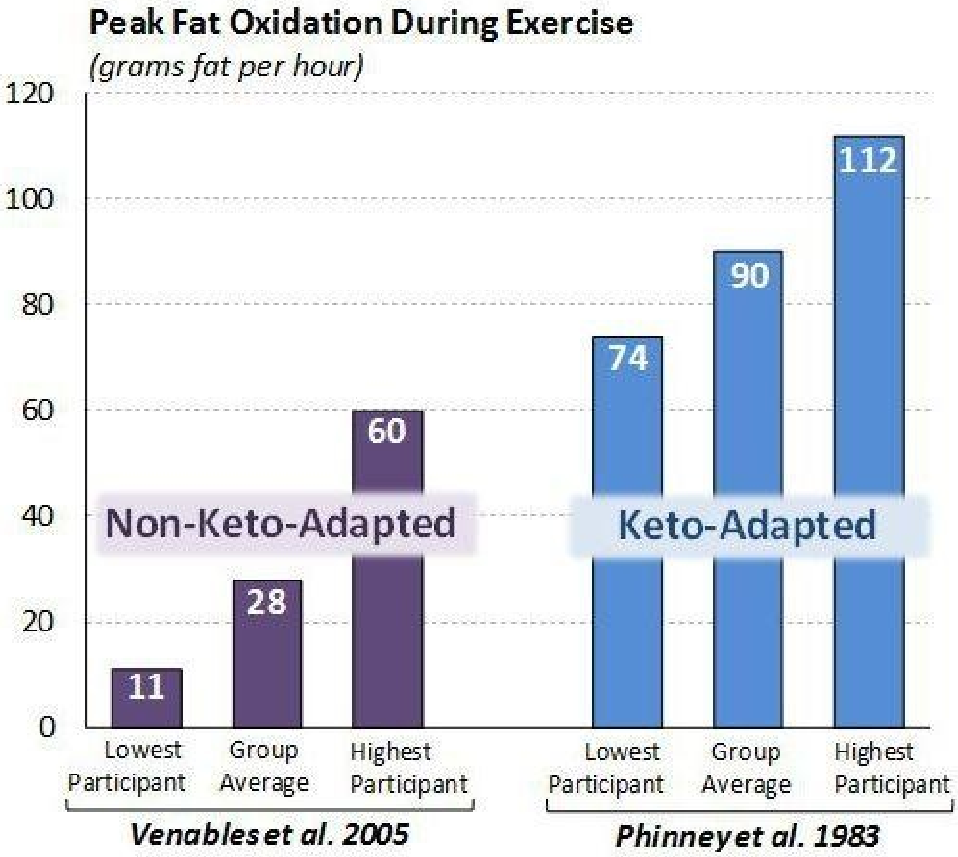
Keto-adaptation is a term coined by Steve Phinney in 1980 to describe the process in which huma metabolism switches over to using almost exclusively fat for fuel (i.e., a combination of fat burne directly and as ketones derived from fat). While well studied and documented mainly in the context starvation, ketone metabolism is not well-understood by most physicians (let alone nutritionist dietitians, trainers, and athletes) as an approach to improve health and performance. This is primari due to the emphasis in standard nutrition training placed on dietary carbohydrates as the preferred fu for physical performance.

Steve's Keto-Adaptation Experiments in Endurance Athletes

Steve first wandered outside the box three decades ago, performing a pair of studies that establishe the ~~human capacity to adapt to very low carbohydrate ketogenic diets[6, 14]. One of these experimen~~ was conducted in lean highly trained cyclists (VO_2max >65 mL/kg/min) who normally consumed high carbohydrate diet. The athletes performed an endurance test to exhaustion on their usual diet an then again after being fed a very low carbohydrate diet for 4 weeks. The diet consisted of 1.75 g/k protein, <10 g carbohydrate, >80% of energy as fat, and was supplemented with minerals includi sodium. Riding a stationary cycle at over 900 kcal per hour, the average performance time was almo identical before (147 min) and after (151 min) adapting to the very low carbohydrate diet.

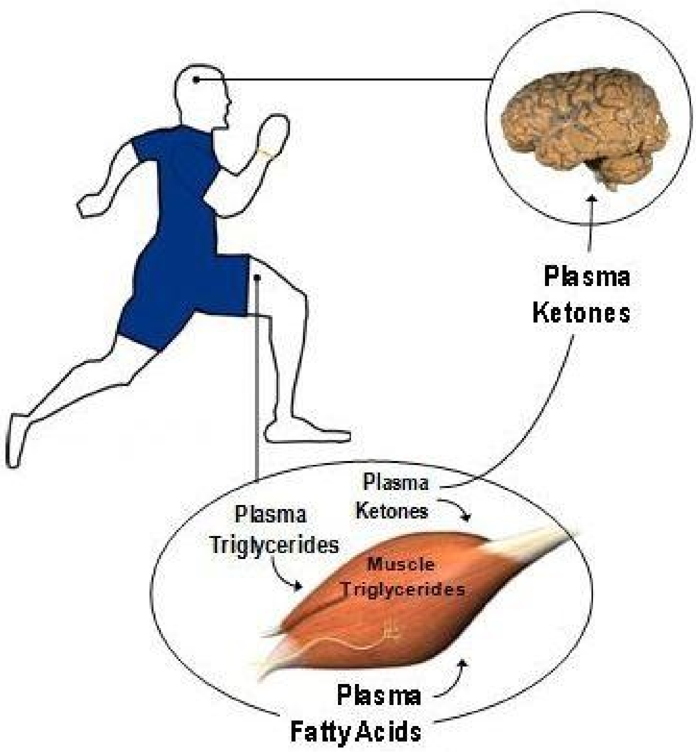
This study demonstrated complete preservation of endurance performance after 4 weeks on a diet th contained virtually no carbohydrate. There was however a dramatic shift in metabolic fuel from heavy dependence on carbohydrate to nearly complete reliance on fat in the keto-adapted cyclists. Th rate of fat use during the exercise test at 64% VO_2max was approximately 90 grams per hour (1 grams per minute). This is over 3 times the average peak fat oxidation recorded by Venables et al[in 300 people that included highly trained individuals with maximal oxygen uptakes exceeding 8 mL/kg/min. Even if you cherry pick and take the participant with the highest peak fat oxidation (60 fat/hour) observed by Venables et al[9], that value is still less than the keto-adapted participant fro Steve's study with the lowest peak fat oxidation (74 g fat/hour). On average keto-adaptation resulte in peak fat oxidation rates of 90 g fat/hour – 50% greater than the highest recorded value for an participant in Venables' study. A couple of Steve's keto-adapted cyclists had fat oxidation rate approaching 2 grams per minute compared to 1 gram per minute when they previously did the san exercise on their high carbohydrate diet. Thus these highly trained athletes, who already had very hig fat oxidation rates, were able to dramatically increase them further – not by changing their trainin but by changing their diet.

Factoid: *Metabolic adaptations to increase peak fat oxidation can be increased by training, but ther remains a large untapped potential in even the most highly trained athlete that can only be achieve by keto-adaptation.*



Despite these intriguing results showing the metabolic plasticity of high level athletes on a very lo carbohydrate diet, for a variety of reasons this dietary strategy has languished for three decades. An for the record, it is noteworthy that Steve's findings have not been refuted by additional research ov that time period. In fact, subsequent studies in rodents[15] and humans[16] have found similar result

Keto-Adaptation De-mystified



Keto-adaptation results in a powerful shift to reliance on lipid-based fuel sources, especially fatty acids for muscle and ketones for the central nervous system.

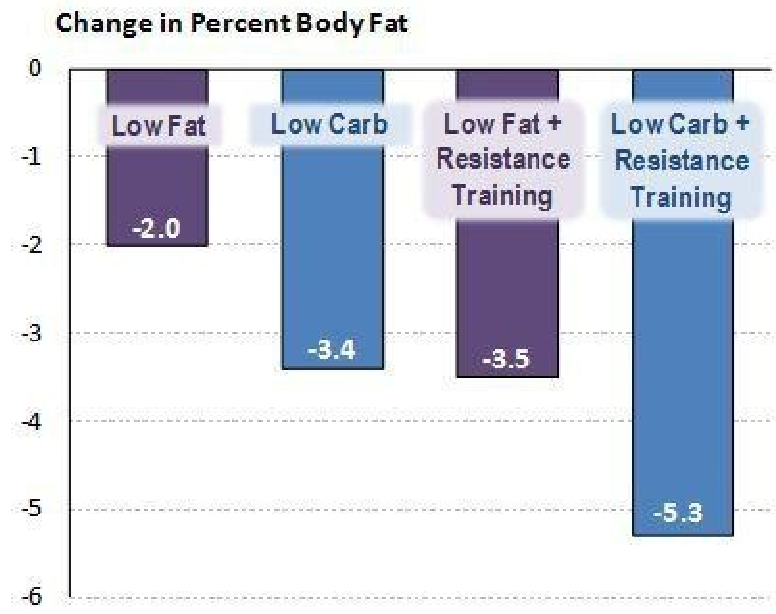
At the most basic level keto-adaptation involves an increase in the body's production and utilizatio of ~~ketones. However, this is a complex and coordinated sequence of highly orchestrated~~ even requiring adaptations in the type of fuel used by most cells in the body. Ketone production occu mainly in the liver in response to a combination of increased delivery of fatty acids and depletion hepatic glycogen reserves. The ketones produced in the liver are then transported by the circulation other cells in the body including muscle and brain. In skeletal muscle, the first few days of ket adaptation result in increased use of both ketones plus fatty acids from a variety of sources (adipose intra-muscular triglycerides, or from circulating very low density lipoprotein particles). Once th process of keto-adaptation is complete (which takes from a few weeks to a month), muscle both at re and during exercise comes to rely heavily on fatty acids. This adaptation of the muscle away fro ketone use spares hepatic ketone production for use by other tissues, especially the brain.

This is a key point. Practically speaking, the brain can burn only glucose or ketones. On a very lo carbohydrate diet, the brain comes to rely on ketones as its primary fuel. Although ketones a preferentially taken up by the brain, because of the large mass of skeletal muscle and the increase blood flow to active muscles during exercise, this delayed shift of the muscles away from ketones an towards fatty acid use is vital to preserving fuel flow to the brain during exercise in the keto-adapte athlete. In part, the time it takes the body to choreograph these changes in whole body fuel flo explain why keto-adaptation takes a couple of weeks rather than just a few hours or days.

Jeff's Keto-Adaptation Experiment With Resistance Training

In addition to Steve's keto-adaptation experiments described in the previous section, Jeff ha performed studies showing that very low carbohydrate diets can support performance of high intensi resistance exercise, resulting in striking improvements in body composition[17]. Overweight me were randomly assigned to either a low-fat diet group that restricted fat to less than 25% of energy a very low–carbohydrate ketogenic diet group that reduced carbohydrate to less than 50 grams per da Half the subjects in each diet group were also randomly assigned to participate in a supervised hig intensity resistance training program while the other half of each group remained sedentary.

The training program was 'nonlinear', alternating among heavy, moderate, and light days. Session were about 45 minutes in duration performed 3–4 days per week for 12 weeks and included a varie of free weight and machine exercises targeting the entire musculature. Training loads were determine using repetition maximum (RM) zones (e.g., 1–10 RM) and were progressively increased over th training period. Body composition was assessed using dual energy x-ray absorptiometry. The lo carbohydrate diet group lost significantly more body fat, and showed greater decreases in bloo insulin levels. Resistance training, independent of diet, resulted in increased lean body mass witho compromising fat loss in both diet groups. The most dramatic reduction in percent body fat was in th low-carbohydrate diet plus resistance training group.



The combination of a very low carbohydrate diet and resistance training results in the largest decreases in percent body fat.

Thus, the combination of a very low carbohydrate diet and resistance training had a profound effect o body composition by maximizing fat loss while increasing lean body mass.

Individual responses in the low carbohydrate plus resistance training group were dramatic in sever cases. One subject lost 20 pounds of fat while gaining 9 pounds of lean body mass. Another one lo 19 pounds of fat while gaining 12 pounds of lean body mass. The greatest fat loss was 30 pounds an this participant gained 9 of pounds lean body mass. In a different study, a 57 year old male (18 pounds, BMI 25 kg/m^2) who was training for a triathlon enrolled in a very low carbohydrate stud Following the initial two week period during which his training intensity was reduced, he reporte having some of the best training sessions of his life. In just 12 weeks, he lost 23 pounds of fat an gained 6 pounds of lean body mass.

Summary

During endurance sports, maintaining high carbohydrate availability is challenging, whereas switchin to lipid fuels with the selective partitioning of ketones among organs could be revolutionary f athletes. Given the vast differences in the capacities of the ‘Fat Tank’ versus the ‘Glycogen Tank even a lean person’s lipid reserves represent a more plentiful and efficient fuel source. The only thin that stands between you and full access to your body fat stores is a brief period of adaptation to a lo carbohydrate diet. Given this background on human metabolism and fuel exchange, we hope it apparent that a low carbohydrate diet that allows you to optimally access your fat stores and increas mitochondrial fat oxidation is a fully rational approach. In the next chapter we discuss the benefits keto-adaptation for athletes in greater detail.

Chapter 4

KETO-ADAPTATION

Metabolic Benefits And Sports Implications

Snap Shot

- Keto-adaptation provides a steady and sustained source of fuel for the brain, thereby protecti athletes from hitting the wall.
- Keto-adaptation may improve insulin sensitivity and recovery from exercise.
- Keto-adaptation spares protein from being oxidized thereby preserving lean tissue.
- Keto-adaptation decreases the accumulation of lactate, contributing to better control of pH ar respiratory function.
- The benefits of keto-adaptation may be relevant for improving endurance, strength/power, ar cognitive performance, as well as speeding recovery.

There are many reasons why people exercise, ranging from recreational, highly competitive, up professional. Similarly, there are many different reasons you might consider keto-adapting b embracing a low carbohydrate lifestyle. In this chapter we describe some of the potential benefits keto-adaptation so you have a better appreciation of how following a low carbohydrate lifestyle mig impact your unique situation.

Metabolic Benefits of Keto-Adaptation for Athletes

There are now many studies documenting the metabolic effects of ketosis, although much of this wo has been done in the context of short-term starvation, type 2 diabetes, and for neurological disorde like childhood seizures. Less research has been done using ketogenic diets in high level athletes, wi the notable exceptions of Steve's and Jeff's original work[6, 17] and that of Tim Noakes[16 Nevertheless, we now have a good understanding of how well formulated ketogenic diets affect variety of metabolic parameters in normal-weight and overweight individuals. This work has focuse on non-athletes and has consistently shown benefits on a broad spectrum of health markers rangi from cholesterol and lipid values to inflammation, blood pressure, and more. In addition, we now hav the practical experience of a growing number of athletes who have adopted a low carbohydrate di from which to draw inferential conclusions [see Chapter 12]. We present the following discussion be provocative, fully aware that a complete understanding of how keto-adaptation affects athlet performance remains to be elucidated.

Brain Fuel. In order for the body to shift from glucose to fat for fuel, there need to be alterations inter-organ fuel exchange – the process that partitions lipid fuels to specific sites for oxidatio Although skeletal muscle has the capacity to take up and oxidize ketones, it appears that over tin muscles switch to using fatty acids provided from blood and probably muscle triglycerides. Th process, a key element of keto-adaptation, allows ketones to achieve levels in the blood that allo them to meet most of the brain's fuel needs. Thus there is a reciprocal relationship between bloo ketones and uptake in muscle; such that when blood ketone levels are low, muscle uptake is hig whereas at higher levels, muscle uptake is reduced. The relationship is different in the brain whe ketones are rapidly taken up by a combination of passive and facilitated diffusion via monocarboxyl acid transporters in proportion to their concentration in the blood[18, 19].

Hunch: *Since monocarboxylic acid transporters function to take up both ketones and lactate, and th* sample content of The Art and Science of Low Carbohydrate Performance