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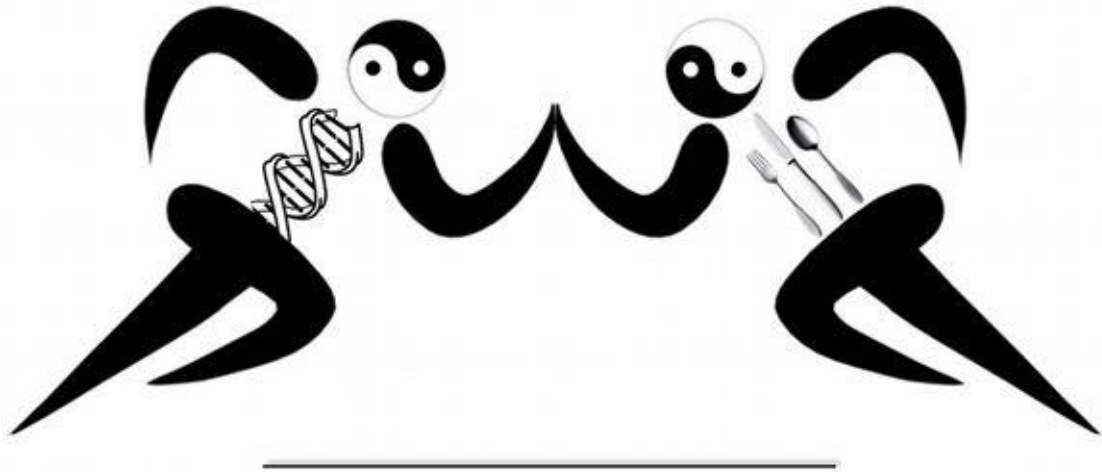


**THE ART AND SCIENCE OF
LOW
CARBOHYDRATE
PERFORMANCE**

THE ART AND SCIENCE OF

LOW CARBOHYDRATE

PERFORMANCE



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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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, we sense even more movement towards a consensus change; whereby the clinical use of low carbohydrate diets in the management of insulin resistance may soon become mainstream. We are genuinely appreciative of the positive and constructive feedback from people who have taken the time to write to us. Many of you asked specifically about exercising during a low carbohydrate diet, and several shared your personal experience with us. Your feedback inspired us to write this book. Now we say to each other “we live in **really** interesting times” because it’s looking like a consensus change on the use of 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 low carbohydrate diets in sports and exercise. We appreciate the thoughtful comments on early drafts from Peter Defty, Peter Davis, Brian Kupchak, Brittanie Volk, and Cynthia Moore. A special thanks to the 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 Jan Wortman.

I (Steve Phinney) wish to thank Dr. Richard Handler who introduced me to cycling, Dr. Edward Horton who got me started in performance research, and Dr. Bruce Bistrian who taught me to regard 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 my family – to Lauren and Eric who put up with my abstruse verbal meanderings during road trips up and down Interstate 5; and to my remarkable wife Huong, without whose intellectual GPS I would have forever lost on the backroads of detail.

I (Jeff Volek) wish to thank my supportive parents who provided me many opportunities to play and compete in sports from a young age, Dr. Linc Gotchalk who coached me in the sport of powerlifting, and Dr. William Kraemer who taught me a deep appreciation for the complexity of exercise science. A special thanks to my co-author Steve, who has inspired and enriched my life beyond what I could

express in words. Above all I want to thank my loving and patient wife, Ana and my two boys, who supported me in spite of the significant time this book project took away from them.

Section 1

THINKING DIFFERENT

Chapter 1

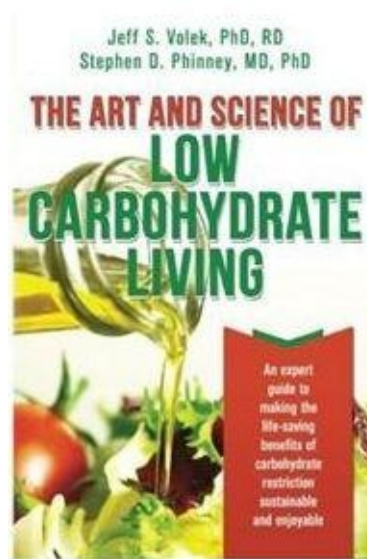
INTRODUCTION

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 diet, there is probably no reason to consider a low carbohydrate diet. If it isn't broke, don't fix it. But if you have hit a plateau, are in a rut, suffer from overtraining, have trouble recovering from your workouts, want to change your body composition, or simply want to experiment with how your body adapts to restricting carbohydrate, then this book is for **“You”**.

“You” might be an elite athlete, coach, trainer, dietitian, physician or scientist. You might be a casual fitness enthusiast or wanna-be athlete. You might be new to exercise, a weekend warrior, or a veteran of the gym but aren't satisfied with your progress or feel drained. If any of these people are You, then 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 for low carbohydrate diets as the preferred approach to managing insulin resistance (aka carbohydrate intolerance). However, on the continuum of insulin resistance, athletes as a group cluster on the side of insulin sensitivity. Thus most athletes do not have anywhere near the same level of carbohydrate 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 majority group-think in sports nutrition holds that all athletes have an obligate need for carbohydrate. But despite having the best intentions, the majority view does not always represent the truth. Besides

exacerbating insulin resistance, *a high carbohydrate diet also locks a person into a dependence on carbohydrate as the dominant fuel for exercise*. And every endurance athlete knows what happens to performance when their carbohydrate tank (at best holding 2000 Calories) runs dry – performance goes down in flames. It's an unfortunate reality that the human body is unable to promptly switch from carbs to fat as its predominant exercise fuel, so once the former is gone, you can't power your performance with fat (even though a carbohydrate-depleted body still has tens of thousands of fat Calories on hand).

The key fact underlying this book is that you can train your body to burn fat by simply changing your 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 the simple answer to why we endorse a low carbohydrate lifestyle for athletes is that this strategy has worked for us and many people we know. More importantly, we have both conducted and published human research that supports this approach, adding to a growing body of literature that now points to the merits of reducing dietary carbohydrates to optimize fat metabolism. We have thus accumulated a unique knowledge base that we want to share so you too may experience it for yourself.

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Do we understand that exercising without carbs is heresy? Absolutely, but think about it from the evolutionary perspective. Before December 17, 1903, about 99% of the population thought that humans could never fly. Not long after that, the proportions for and against the possibility of human flight were reversed. In the 6000 years since small pockets of humanity first developed agricultural carbohydrates, most of us have come to believe that agricultural carbohydrates are necessary for health, and particularly for sports performance. Is this indeed true? Or is it more akin to the world view on the day before the Wright Brothers flew? Perhaps most of us are victims of Stockholm Syndrome, having emotionally 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 are addictive. Whether the human brain's response to carbohydrate withdrawal is characteristic of a true addiction response remains a topic of debate. However it is true that, from a functional perspective, once you light your metabolic fire with carbohydrates, it is hard to ignore the incessant signals to keep 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-acre production that dietary carbohydrates deliver, allowing humanity to burgeon way beyond those 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, by definition, about as different from the general population as you can get. By whatever combination of inborn capabilities plus intense training and commitment, athletes transcend the population's norms both in physical performance and in nutrient needs. From this perspective, the correct combination of foods which best make and sustain athletic prowess must be considered as potentially unique rather than 'normal'.

Jared Diamond, the acclaimed geographer and author, notes that with the advent of agriculture in Southern Europe, the average height of the population decreased by six inches, and the average longevity declined by 10 years[2]. Similar effects were observed in Native North Americans who

agriculture was adopted a thousand years before Columbus discovered they were there. Holdouts against this agricultural trend, such as those nomadic cultures (e.g., Osage, Kiowa, Blackfeet, Shoshone, Assiniboine, and Lakota) that lived almost solely on the buffalo, were 6-12 inches taller than the European settlers whose sustenance depended on wheat and corn[3]. Interestingly, the Masai in East Africa also lived as nomadic herders on a diet of meat and milk, and they too were known for their unusual height and physical prowess.

These observations support the concept that a diet consisting mostly of fat and protein can support remarkable growth, physical well-being and function – in essence, promoting the capabilities of the 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 just the two of us, but the greater ‘we’ encompassing many colleagues) are now wrapping up a remarkable decade of human research on diets lower in carbohydrate and commensurately higher in fats and protein. In the last 10 years, ‘we’ have discovered that:

- Low carbohydrate diets are anti-inflammatory, producing less oxidative stress during exercise and more rapid recovery between exercise sessions.
- Physiological adaptation to low carbohydrate living allows much greater reliance on body fat, not just at rest but also during exercise, meaning much less dependence on muscle glycogen and less need to reload with carbohydrates during and after exercise.
- Low carbohydrate adaptation accelerates the body’s use of saturated fats for fuel, allowing a high intake of total fats (including saturates) without risk.
- At the practical level, effective training for both endurance and strength/power sports can be done by individuals adapted to carbohydrate restricted diets, with desirable changes in body composition and power-to-weight ratios.

A low carbohydrate lifestyle is not necessarily ideal for every athlete, but it is clearly desirable for some. To make an informed choice, however, every individual needs a basic understanding of how low carbohydrate diets function to support human physiology. Much of this information has been covered in our recently published book “The Art and Science of Low Carbohydrate Living”. In addition, however, both the athlete and coach/trainer need to understand how to integrate this diet with training 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 of individual athletes, whether your intent is competition or recreation. This goal is efficiently met by providing you with 12 concise chapters with a minimum of theory and a maximum of practical direction. After considering this information and making appropriate changes in your diet, perhaps 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 used initially, they tend to become an ‘alphabet salad’ in later chapters. To alleviate that problem, we have 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 of carbohydrate fuel (~2,000 kcal).
 - Fueling tactics that emphasize carbohydrate-based diets and sugar-based supplements bias your metabolism towards carbohydrate while simultaneously inhibiting fat mobilization and utilization.
 - This suppression of fat oxidation lasts for days after carbohydrates are consumed, not just the few hours following their digestion when insulin levels are high.
 - This high carbohydrate paradigm produces unreliable results, especially during prolonged exercise when body carbohydrate stores are exhausted.
 - In order to sustain a high level of performance under conditions of glycogen depletion and decreased glucose availability, cells must adapt to using fat fuels. This process is referred to as 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 the context of data obtained after keto-adaptation.
-

It is accepted dogma within the science of sports nutrition that carbohydrates are essential and that they are the preferred fuel for athletes. Indeed, over the last 45 years a great deal of progress has been made in understanding how to use carbohydrates to optimize the metabolic response to physical activity. This understanding in turn has driven development of nutritional approaches to prevent fatigue and improve exercise tolerance. We don't want to play down the extraordinary work of researchers who have contributed to this knowledge. However it is instructive to point out that even since the observation over four decades ago that low muscle glycogen was associated with fatigue, most of that progress has been focused on ways to enhance glycogen levels and carbohydrate oxidation (e.g., carbohydrate loading, use of multiple sources of sugars, etc.). Little effort has been devoted to developing methods to decrease the body's dependence on carbohydrate during physical activity. The result is a billion dollar sports beverage and supplement industry that aggressively promotes rapidly absorbed sources of carbohydrate before, during, and after exercise. We contend that there's a limit to what can be achieved by consuming sugary drinks and gels in hopes of delivering 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 what we know about human physiology? Not exactly – it's more a case of willful neglect. The belief that carbohydrate is the ideal fuel source and that a high carbohydrate diet is optimal for all athletes is

self-reinforcing concepts that have been passed down to at least a couple generations of sports scientists. Many of the experiments conducted during that time were designed in a specific manner and data interpreted within a narrow mindset to support and confirm the high carbohydrate paradigm. The result is a classic example of confirmation bias – the tendency to favor information that confirms a preconception or hypothesis regardless of whether it is true.

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

Fueling Exercise

[Adenosine tri-phosphate \(ATP\)](#) is the chemical energy that fuels body processes including muscle contraction. It's literally the energy that causes your muscle fibers to contract and produce force. At rest we are constantly breaking down and synthesizing ATP. When you exercise vigorously, ATP demands increase several-fold. Since we can't store (nor do we eat) ATP in appreciable amounts, exercise causes an immediate need to rapidly make ATP from other energy sources. The two primary fuels our bodies draw on to do this are carbohydrate and fat. How the body chooses the proportion of carbohydrate and fat to use for fuel is complex, but one factor that has a consistent and profound effect is the availability of carbohydrate. The more carbs that are available, the more carbs the body 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 functional perspective, this is curious because carbohydrates cannot be stored in large amounts in the body. When we talk about storing and burning carbohydrate, the 'common energy currency' used by the body is glucose. Glucose can be metabolized directly to make ATP, and glucose can also be stored in modest amounts as glycogen in skeletal muscle, and to a lesser extent in liver. On average, the maximum glycogen store you can accumulate is between 400-500 grams. And since 1 gram of carbohydrate equals 4 kcal, you max out at about 1600-2000 kcal in your carbohydrate fuel tank. Each gram of glycogen is also stored with a couple grams of water. If you carry more muscle mass, are well trained, and eat a high carbohydrate diet, your glycogen stores might be increased by up to another 50% or so, but the total amount of carbohydrate available in the body is still relatively low compared to available fat stores.

Fat Fuel Tank

Which Fuel Tank Do You Want Access To?

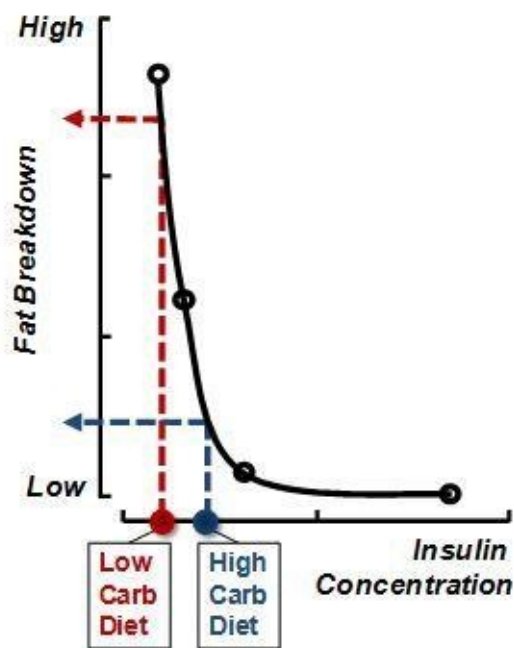


Fat, or more specifically fatty acids, are stored in the body as triglycerides consisting of three fatty acids linked to a single 3-carbon glycerol. Triglycerides coalesce into fat droplets that occupy ~85% of adipose tissue cells (i.e., fat cells, aka ‘adipocytes’). Unlike our limited storage of glycogen,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

During prolonged exercise when body stores of carbohydrate as glycogen are depleted, there is an increasing dependence on the liver to maintain blood glucose levels. This is not just to provide the exercising muscles with glucose, but also to support other normal body functions, especially those of the central nervous system. Decreased carbohydrate availability, particularly for the brain, marks the central event resulting in a sharp decline in physical and mental performance (i.e., *hitting the wall* or *bonking*). The current practice of carbohydrate loading increases glycogen stores and is often accompanied by ingestion of sugar-based sport drinks and gels during exercise. These carb-based fueling tactics may delay the onset of hitting the wall, but for most athletes extending beyond marathon-duration events, they will still crash and burn despite having literally many thousands of Calories worth of fuel tucked away in their fat cells. Why can’t this surplus of fat fuel be utilized even at a time when the body desperately needs it? Simply put, it can be accessed, but it takes a few weeks of carbohydrate restriction during which time the body becomes significantly more efficient at 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. As the name implies, this process involves the conversion of fat to ketones in the liver, and these ketones help supply the brain with energy when glucose levels fall. This affords even a very lean (10% body fat) athlete access to more than 40,000 kcal from body fat, rather than starting a prolonged event 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 is removing the fatty acid from the glycerol backbone (aka, fat breakdown or lipolysis). This is achieved by the enzyme hormone-sensitive lipase. Although many factors *stimulate* the activity of hormone-sensitive lipase (e.g., epinephrine, norepinephrine, growth hormone, activated thyroid hormone), fat breakdown is principally controlled by the single hormone that *inhibits* its activity. That hormone is insulin. In other words, insulin is the primary gate-keeper of body fat. If your insulin levels are consistently high, fat usage is effectively blocked.

The primary nutrient that stimulates insulin is dietary carbohydrate. Some forms of carbohydrate stimulate insulin more than others. Thus, consumption of insulin-stimulating carbohydrates is a 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 line. Instead it's a steep curve, which means that fat release plummets with just a modest rise in insulin, such as those stimulated by most sports beverages. Looking at it from another perspective, near the bottom on the blood insulin range, just small decreases in insulin translate into large increases in fat breakdown and fat oxidation[4]. Thus, focusing on keeping insulin low is associated with significant changes in fat metabolism, favoring decreased storage and increased fat oxidation. In case you're wondering, insulin's effect on fat breakdown does not take days or even hours, its effect is virtually immediate. Keto-adaptation, however, is not immediate. Keeping insulin low is a first step in increasing fat availability, but to maximize fat burning the body requires at least a couple weeks of 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 better. Insulin's effects are not limited to promoting glucose uptake and suppressing fat breakdown. In addition to promoting storage of fat, insulin also potently and rapidly inhibits both blood fatty acid 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 story. Fatty acids then need to be delivered to tissues like active muscle. Triglycerides and fatty acids are not water soluble, so in the blood, fatty acids released from fat cells are attached to a protein called albumin and delivered to muscle. Fat is taken up into muscle cells through specific transport proteins and delivered to ATP-generating organelles within the cell called mitochondria. Transport of fatty acids into the mitochondria is highly regulated, and some might argue that this is the rate limiting step in oxidizing fat. The other fate for fatty acids taken up by muscle, particularly during periods of rest, is conversion back to triglyceride within the muscle cell itself where it is stored as lipid droplets for later use.

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

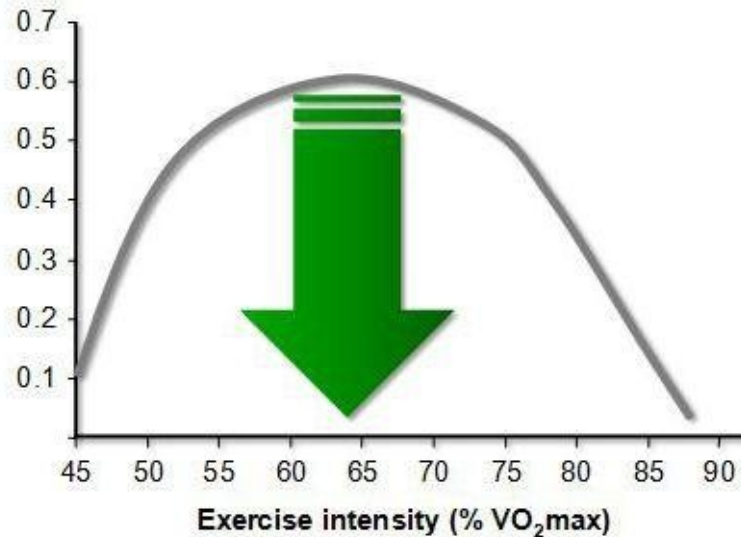
There you have it, the path of a fatty acid molecule from storage in fat cells to oxidation in muscle. But where does dietary fat fit in? Dietary fat is absorbed from your small intestine and packaged into triglycerides into a blood-borne particle called a chylomicron. These are acted upon by fatty acid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

Exercise Intensity and Peak Fat Oxidation

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

If you start exercising lightly and gradually increase the intensity while simultaneously measuring the contribution of fat and carbohydrate to energy use, you will find that the peak rate of fat burning (grams of fat oxidized per minute or per hour) occurs *on average* at about 50% of [maximal oxygen consumption \(VO₂max\)](#) if you're untrained and at 65% [VO₂max](#) if you're trained[5]. Exercise hard and although power output increases, the contribution of fat decreases, forcing carbohydrate to become the predominant fuel source. 65% of VO₂max is an intensity most endurance athletes can easily maintain for several hours. This means that if you exercise above this threshold, fat oxidation normally cannot increase to meet the greater energy demands. In fact, as you push up close to maximal oxygen capacity, there is a rather sharp decline in fat oxidation – not just its proportion, but in absolute grams per minute as well. This is an important detail that requires greater inspection because this line of reasoning is often used as justification to teach away from low carbohydrate/high fat diets for athletes who exercise at or above 65% VO₂max.

Fat oxidation
(g/min)



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

Second, and more importantly, there is a great deal of variability between individuals consuming moderate to high carbohydrate diets (both trained and untrained) in their capacity to burn fat at rest and during exercise[8]. Studies almost always highlight average responses for a group, but given such variability between individuals, hardly anyone responds like the group average. Thus, when dealing with individuals, it's more interesting to look at the tails of the distribution (i.e., the outliers at the high and low ends of a group). For example, in a study of 300 people, peak fat oxidation ranged between 10 and 60 grams of total fat burned per hour. For some people peak fat oxidation occurred at very low exercise intensities (e.g., 25% of VO₂max) whereas in others it occurred up to 77% VO₂max[9].

Factoid: *There are remarkable differences among individuals in both the magnitude of peak fat 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 of fat burned per hour) represents an absolute ceiling, or whether humans have the capacity to exceed this level? The answer, it turns out, has been hiding in plain sight for almost 30 years. Not only can

this 60 gram per hour ‘butter ceiling’ be cracked, it can be totally splattered. Turn to the next chapter for the key to unleashing your maximal fat burning potential. The reward for many readers will be improved endurance performance as well as better control over your body composition (as in no loss 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 that show accelerated fat burning and, as a result, extraordinary endurance capacity. Yes, these are animals; and yes, there are limits to their direct relevance vis-a-vis human exercise metabolism because of inherent species differences. But if nothing else, they do provide evidence for what is possible in the context of mammalian physiology. It’s also interesting that these super animal athletes 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 Mice” owing to their ability to perform prodigious amounts of exercise[10]. Dr. Richard Hanson and his laboratory group at Case Western Reserve University made this serendipitous discovery during experiments initially aimed at elucidating the role of [PEPCK \(phosphoenolpyruvate carboxykinase\)](#), a key enzyme involved in the pathway that converts non-carbohydrate substances into glucose. They 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 easily distinguished from normal mice because they were noticeably more active, ate more food, but were nonetheless leaner. They were up to 10 times more active, sometimes exercising continuously for up to 6 hours. This incredible propensity to exercise was accompanied by a remarkable capacity to burn fat despite having less subcutaneous and visceral fat stores. These mice had high levels of stored triglycerides in their muscles and proportionately more mitochondria to burn that fat. Consistent with accelerated fat burning, these animals also showed little accumulation of lactate during exercise compared to control mice, indicating much less reliance on muscle glycogen and glucose for fuel. Dr. Hanson’s observations raise the question: could there be humans with increased muscle PEPCK, and 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 active, likely because there is better total body fuel flow based on fatty acids and ketones. Could this be 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 Iditarod. Successful dogs show an unusual fatigue-resistance that develops over the course of the event that spans 8-10 days. These unique athletes are able to pull their sleds more than 100 miles per day for consecutive days in environmentally harsh conditions. The best dogs transform their metabolism in a way that avoids depletion of energy substrates and allows for rapid recovery. They actually replenish muscle glycogen over the course of consecutive days of strenuous exercise. Clearly they develop a profound ability to utilize lipid fuel such as muscle triglycerides (which shows a progressive depletion over several days of exercise) as well as circulating fatty acids and ketones. Dogs are also known to 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 know 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

Snap Shot

- Ketones are an important lipid-based fuel source, especially for the brain, when dietary carbohydrates are restricted.
 - The process of keto-adaptation (switching over to using primarily fatty acids and ketones) can 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 human fat oxidation have been significantly underestimated.
 - Keto-adapted individuals can do resistance training, and show profound improvements in body composition.
-

Over the last four decades, carbohydrate-rich diets have been vigorously promoted to athletes based on the rationale that high carbohydrate oxidation rates are preferable to high fat oxidation rates, and therefore maintaining a high muscle glycogen level is essential to achieve optimal performance. As you might guess by now, we've just got to say, "wait a minute!" Over these same four decades, we've seen enough foot prints in the sand to lead us to the exact opposite conclusion – that a high carbohydrate diet may be neither required nor desired for many athletes. Some might characterize this as a tectonic shift in sports nutrition thinking. We just consider this to be sound reasoning and part of 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 diets using brief periods of intense exercise, one could credibly argue the superiority of a high carbohydrate diet. Today, however, a combination of time-tested experience and recent research data supports the conclusion that if humans are given two or more weeks to adapt to a well-formulated low carbohydrate diet, they can deliver equal or better endurance performance compared to the best high carbohydrate diet strategy. Combine this with the observational evidence of ultra-endurance athletes performing at consistently high levels using varying degrees of carbohydrate restriction to optimize 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 athletes, the benefits of keto-adaptation on exercise performance and recovery have yet to be fully explored in humans. There have been a number of nutritional strategies aimed at increasing fat burning during exercise such as caffeine, carnitine, ephedra, medium chain triglycerides, green tea extract, and hydroxycitric acid to name a few. Use of these supplements may mildly elevate fat burning; however, they pale in comparison to the dramatic shift that occurs after a couple of weeks of adaptation to a 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 organic acids were first discovered in urine of uncontrolled diabetic patients in the latter half of the 19th century. Although a much different picture has slowly emerged over the last 100 years, elucidating an important role for ketones in human health, the negative connotation associated with their debut has been hard to shake. This is both ironic and unfortunate because dietary strategies to increase ketone production are now linked to improvements in several medical conditions, and perhaps sports 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 been 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 \(BOHB\)](#) and [acetoacetate \(AcAc\)](#). BOHB and AcAc are made in the liver from fatty acids, and chemically they retain some similarities to the fatty acids from whence they come. However, being much smaller molecules, they are water soluble, making them easier to transport in the blood (more like the simple sugars whose functions they in part replace). Even when we eat a lot of carbohydrates, ketones are naturally present in our blood at relatively low levels, but their production increases in response to decreased carbohydrate availability and accelerated rates of fatty acid delivery to the liver. This is perfectly natural and in fact represents a vital adaptation in fuel partitioning when carbohydrate intake 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 to eating a low carbohydrate diet – was first voiced by a US Army surgeon and Arctic explorer, Lt. Frederick Schwatka, in the early 1880s. This historical cornerstone, lost for a century, was referenced by Dr. Phinney in his watershed 1983 study of bicycle racers adapted to an Inuit diet*[6, 14].

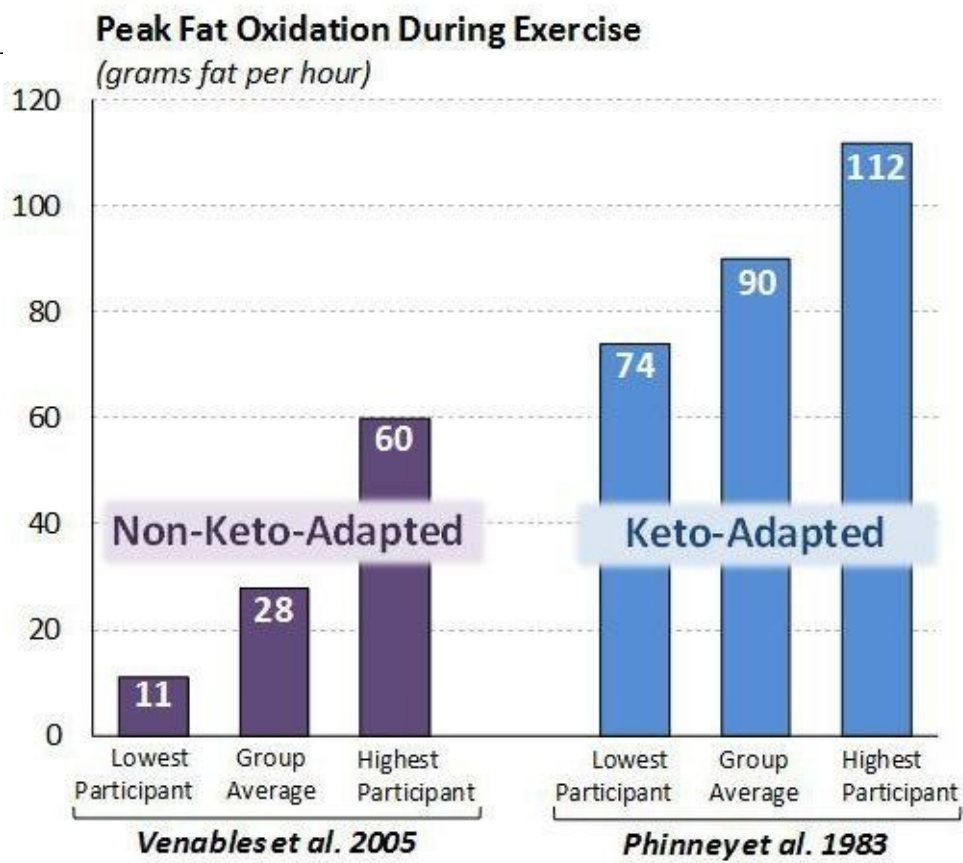
Keto-adaptation is a term coined by Steve Phinney in 1980 to describe the process in which human metabolism switches over to using almost exclusively fat for fuel (i.e., a combination of fat burned directly and as ketones derived from fat). While well studied and documented mainly in the context of starvation, ketone metabolism is not well-understood by most physicians (let alone nutritionists, dietitians, trainers, and athletes) as an approach to improve health and performance. This is primarily due to the emphasis in standard nutrition training placed on dietary carbohydrates as the preferred fuel 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 established the human capacity to adapt to very low carbohydrate ketogenic diets[6, 14]. One of these experiments was conducted in lean highly trained cyclists ($VO_2\text{max} >65 \text{ mL/kg/min}$) who normally consumed a high carbohydrate diet. The athletes performed an endurance test to exhaustion on their usual diet and then again after being fed a very low carbohydrate diet for 4 weeks. The diet consisted of 1.75 g/l protein, <10 g carbohydrate, >80% of energy as fat, and was supplemented with minerals including sodium. Riding a stationary cycle at over 900 kcal per hour, the average performance time was almost identical before (147 min) and after (151 min) adapting to the very low carbohydrate diet.

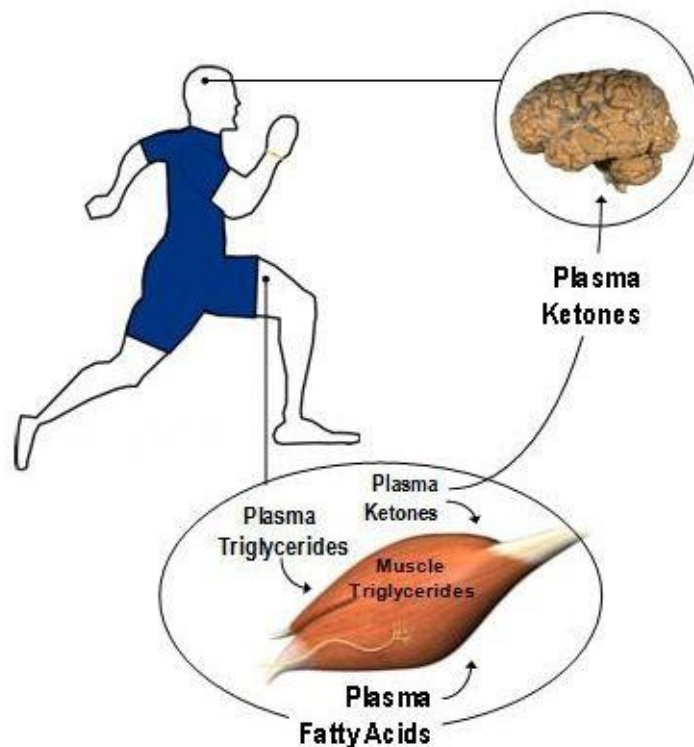
This study demonstrated complete preservation of endurance performance after 4 weeks on a diet that contained virtually no carbohydrate. There was however a dramatic shift in metabolic fuel from a heavy dependence on carbohydrate to nearly complete reliance on fat in the keto-adapted cyclists. The rate of fat use during the exercise test at 64% $VO_2\text{max}$ was approximately 90 grams per hour (1.5 grams per minute). This is over 3 times the average peak fat oxidation recorded by Venables et al[9] in 300 people that included highly trained individuals with maximal oxygen uptakes exceeding 80 mL/kg/min. Even if you cherry pick and take the participant with the highest peak fat oxidation (60 g fat/hour) observed by Venables et al[9], that value is still less than the keto-adapted participant from Steve's study with the lowest peak fat oxidation (74 g fat/hour). On average keto-adaptation resulted in peak fat oxidation rates of 90 g fat/hour – 50% greater than the highest recorded value for any participant in Venables' study. A couple of Steve's keto-adapted cyclists had fat oxidation rates approaching 2 grams per minute compared to 1 gram per minute when they previously did the same exercise on their high carbohydrate diet. Thus these highly trained athletes, who already had very high fat oxidation rates, were able to dramatically increase them further – not by changing their training but by changing their diet.

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



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

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 utilization of ketones. However, this is a complex and coordinated sequence of highly orchestrated events requiring adaptations in the type of fuel used by most cells in the body. Ketone production occurs mainly in the liver in response to a combination of increased delivery of fatty acids and depletion of hepatic glycogen reserves. The ketones produced in the liver are then transported by the circulation to other cells in the body including muscle and brain. In skeletal muscle, the first few days of keto-adaptation result in increased use of both ketones plus fatty acids from a variety of sources (adipose tissue, intra-muscular triglycerides, or from circulating very low density lipoprotein particles). Once the process of keto-adaptation is complete (which takes from a few weeks to a month), muscle both at rest and during exercise comes to rely heavily on fatty acids. This adaptation of the muscle away from 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 low carbohydrate diet, the brain comes to rely on ketones as its primary fuel. Although ketones are preferentially taken up by the brain, because of the large mass of skeletal muscle and the increase in blood flow to active muscles during exercise, this delayed shift of the muscles away from ketones and towards fatty acid use is vital to preserving fuel flow to the brain during exercise in the keto-adapted athlete. In part, the time it takes the body to choreograph these changes in whole body fuel flow 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 has performed studies showing that very low carbohydrate diets can support performance of high intensity resistance exercise, resulting in striking improvements in body composition[17]. Overweight men were randomly assigned to either a low-fat diet group that restricted fat to less than 25% of energy or a very low-carbohydrate ketogenic diet group that reduced carbohydrate to less than 50 grams per day. Half the subjects in each diet group were also randomly assigned to participate in a supervised high 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. Sessions were about 45 minutes in duration performed 3-4 days per week for 12 weeks and included a variety of free weight and machine exercises targeting the entire musculature. Training loads were determined using repetition maximum (RM) zones (e.g., 1-10 RM) and were progressively increased over the training period. Body composition was assessed using dual energy x-ray absorptiometry. The low carbohydrate diet group lost significantly more body fat, and showed greater decreases in blood insulin levels. Resistance training, independent of diet, resulted in increased lean body mass without compromising fat loss in both diet groups. The most dramatic reduction in percent body fat was in the low-carbohydrate diet plus resistance training group.

Change in Percent Body Fat



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 on body composition by maximizing fat loss while increasing lean body mass.

Individual responses in the low carbohydrate plus resistance training group were dramatic in several cases. One subject lost 20 pounds of fat while gaining 9 pounds of lean body mass. Another one lost 19 pounds of fat while gaining 12 pounds of lean body mass. The greatest fat loss was 30 pounds and this participant gained 9 of pounds lean body mass. In a different study, a 57 year old male (180 pounds, [BMI](#) 25 kg/m²) who was training for a triathlon enrolled in a very low carbohydrate study. Following the initial two week period during which his training intensity was reduced, he reported having some of the best training sessions of his life. In just 12 weeks, he lost 23 pounds of fat and gained 6 pounds of lean body mass.

Summary

During endurance sports, maintaining high carbohydrate availability is challenging, whereas switching to lipid fuels with the selective partitioning of ketones among organs could be revolutionary for 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 thing that stands between you and full access to your body fat stores is a brief period of adaptation to a low carbohydrate diet. Given this background on human metabolism and fuel exchange, we hope it is apparent that a low carbohydrate diet that allows you to optimally access your fat stores and increase mitochondrial fat oxidation is a fully rational approach. In the next chapter we discuss the benefits of 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 protecting 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](#) and respiratory function.
 - The benefits of keto-adaptation may be relevant for improving endurance, strength/power, and cognitive performance, as well as speeding recovery.
-

There are many reasons why people exercise, ranging from recreational, highly competitive, up to professional. Similarly, there are many different reasons you might consider keto-adapting to embracing a low carbohydrate lifestyle. In this chapter we describe some of the potential benefits of keto-adaptation so you have a better appreciation of how following a low carbohydrate lifestyle might 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 work has been done in the context of short-term starvation, type 2 diabetes, and for neurological disorders like childhood seizures. Less research has been done using ketogenic diets in high level athletes, with 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 a variety of metabolic parameters in normal-weight and overweight individuals. This work has focused on non-athletes and has consistently shown benefits on a broad spectrum of health markers ranging from cholesterol and lipid values to inflammation, blood pressure, and more. In addition, we now have the practical experience of a growing number of athletes who have adopted a low carbohydrate diet from which to draw inferential conclusions [see [Chapter 12](#)]. We present the following discussion to be provocative, fully aware that a complete understanding of how keto-adaptation affects athletic 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 in inter-organ fuel exchange – the process that partitions lipid fuels to specific sites for oxidation. Although skeletal muscle has the capacity to take up and oxidize ketones, it appears that over time muscles switch to using fatty acids provided from blood and probably muscle triglycerides. The process, a key element of keto-adaptation, allows ketones to achieve levels in the blood that allow them to meet most of the brain's fuel needs. Thus there is a reciprocal relationship between blood ketones and uptake in muscle; such that when blood ketone levels are low, muscle uptake is high whereas at higher levels, muscle uptake is reduced. The relationship is different in the brain where ketones are rapidly taken up by a combination of passive and facilitated diffusion via monocarboxylic 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 the*

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