

The Effects of Low Carbohydrate Diets on Endurance Performance

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Introduction

Endurance exercise is a common type of training for athletes and people that simply want to stay in shape. This type of conditioning is classified as exercise that is low in intensity but prolonged in time. Participants do not exceed a VO_2 of about 50%. Some forms of endurance exercise that will be focused on in this study are long distance cycling and running. Cyclists participate in “century rides” of 100 miles in a day or bike distances of around 4,000 miles over a few weeks. There are many cyclists that have biked across America, an equivalent of 3,500 to 5,000 miles depending on the route. Runners compete in ultra-marathons, marathons, and half marathons for long-distance competition. Endurance activities of that scale require intense training, and some trainers and athletes argue that a specific diet is even more important.



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When training, it is a common to equate your needs to a high carbohydrate diet (Cook, 2007).

Practices like carbohydrate loading before a competition or pasta feeds after a big race are customary for athletes. Despite these traditions, a trend of low carbohydrate diets is arising.

People with certain disorders, those wishing to lose weight, and competitors looking for a new edge are turning to diets that focus more on the other fuel sources, like fats and proteins, and minimize carbohydrates.

Restrictive diets are becoming more popular for treating cases of Celiac's disease, irritable bowel syndrome, hormone disorders, cancers, and a variety of other health concerns. People searching for diet based treatments to their conditions try to eliminate gluten, wheat products, starch, and sugars from their diets which take away many carbohydrate sources (Williams et al, 2012). This strategy is referred to as an

elimination diet. Many dieters have also tried low carbohydrate diets, like Atkin's or the Zone, to lose weight. These programs aim to shift diets to be primarily proteins and fats with some complex carbohydrates through vegetables, fruits, and minimal grains (Williams et al, 2012) With this nutrition fad, the question arises if this could affect performance, particularly for endurance exercise. Does the classic practice of high carbohydrate diets for athletes lead to better endurance performance, or will the other fuels suffice and even be more beneficial?

Fast Facts

- 10-15% of the population is affected by digestive disorders that fall under Irritable Bowel Syndrome, which can be helped through diet.
- Low carbohydrate diets as well as probiotics have been proven to help digestive distress.
- High fat diets have positive effects on endurance exercise such as more power output over prolonged time and longer time until exhaustion.
- The most consistent, attractive outcome of high fat diets is less body fat percentage.

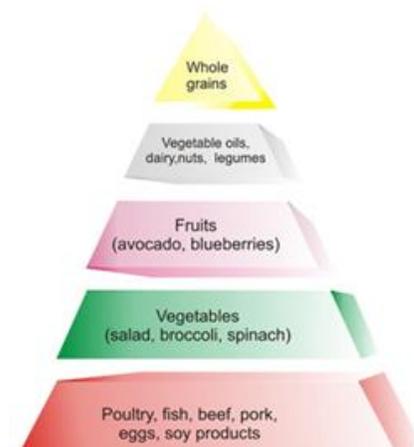


Figure 1. [The Atkins Diet Pyramid.](#)

Literature Review

The available literature has shown that high fat diets can achieve equal or greater performance for endurance exercise but poorer performance for high-intensity exercise when compared with high carbohydrate diets. This was proven by testing trained endurance runners and cyclists after they adhered to high carbohydrate and high fat diets to observe performance characteristics.

Cook addressed the common perception among athletes that diets high in carbohydrates are best for optimal performance. It is often suggested that 7-10 g/kg/day of carbohydrates are necessary for endurance athletes to supply muscle and liver stores (Cook).



Fast Facts

- Studies have shown that glycogen content at the beginning of moderate to low intensity exercise does not have an effect on performance.
- Glycogen can be stored in the muscle up to 300-400 grams and in the liver at about 70-100 grams.
- Fat on the other hand can be stored in adipocytes and muscle that add up to 14,000-15,000 grams.
- It is advantageous for endurance athlete's body to have high fat oxidation capacity.
- The body will release hormones during exercise to cause a glucose sparing effect so the body uses more fat and protein as fuel.

In the studies from Kavouric, Lambert, and Phinney on endurance runners and cyclists, all the researchers found that glycogen stores were higher at the beginning of exercise when the subjects were on high carbohydrate diets compared to high fat diets. Interestingly, the starting glycogen levels did not affect the endurance performance. The subjects were able to perform as much work (Kavouras, 2004; Phinney, 2004) and in some cases more prolonged work (Lambert, 1994) with the lower glycogen levels from a high fat diet. The average glycogen store is 300-400 grams in muscle and 70-100 grams in the liver (Howley & Powers, 2012). Unfortunately those stores could be depleted in prolonged exercise if there was not another fuel source. Because of the limited amount of glucose available, Burke explains that endurance athletes should have high fat oxidation to spare the glucose (2007). The body has natural glucose sparing tendencies during exercise as a survival mechanism to save its energy source and make sure the brain gets plasma glucose, its only useable source of fuel. The effects of a high fat diet mimic those of the body's natural response to exercise; it increases fat oxidation, mitochondrial density, use of muscle triglycerides, and uptake of free fatty acids (Cook, 2007). Because of those affects, researchers hypothesized having a diet with high fat percentage would allow athletes to exercise for longer because they would not have to use glucose stores as quickly. The body would have more fat to use from the diet, and would also have the right enzymes to break down fat stored as adipose. (Williams et al, 2013) Theoretically this would enable athletes to exercise longer and burn more fat during exercise and rest.

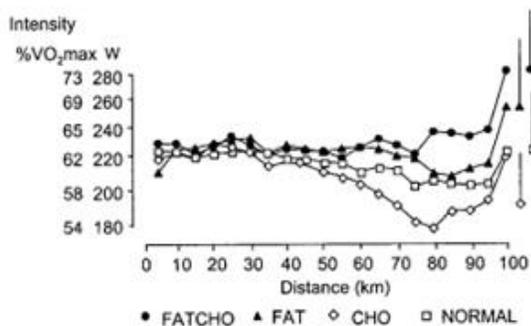


Fig 3. Power output during 100-km time trial. Data points are mean power for each 5-km split. Vertical bars are means of the between-subject standard deviations for each 5-km sample point. The sharp increase in power during the last 5 km of the time trial represents the final surge to complete the time trial.

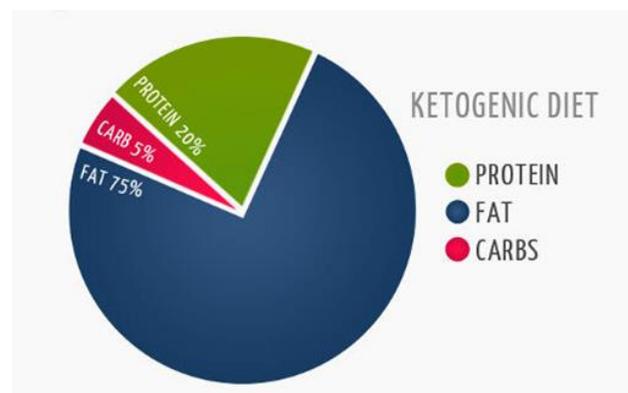
When tested on elite cyclists, one of the results indicating that high fat diets can be advantageous was found by Lambert when he tested five endurance trained cyclists on a high fat (67%) and low carbohydrate (7%) diet for two weeks and a high carbohydrate (74%) and low fat (12%). The subjects on the high fat diet doubled time to exhaustion in moderate intensity exercise, classified as 60% VO₂ max. Lambert infers that it is due to a lower respiratory exchange ratio and less carbohydrate oxidation. (1994)

Zajac et al had similar findings when he tested eight trained cyclists after they had been put on a ketogenic diet. Like Lambert, Zajac et al reports lower respiratory exchange ratios during rest and during exercise when the subjects were on the high fat diet. Also, when the subjects on the ketogenic diet performed prolonged cycling, over 105 minutes, their measured VO₂ max increased (2014). The VO₂ of an athlete is considered one of the best indicators of fitness.

Another common finding that supports high fat diets is that athletes can sustain power output over more time.

Rowlands found that the elite cyclists he studied were able to lessen the decline in power output when they were on a high fat diet compared to when they were on a high carbohydrate diet. He estimated that for every 10% increase in energy from fat there was a 2% increase in power output. The cyclists in Rowland's study were able to exert one to two times greater power output in the last five kilometers of a 100 kilometer test while on a diet with 66% fat and 15% carbohydrate (2002). Zajac et al supports this finding in their study by measuring an increased work output over time. His subjects were able to perform more work in a prolonged time test while on a ketogenic diet versus a mixed diet (2014).

Cook claims that perhaps the greatest advantage of a high fat diet though is the effect it has on body composition (2007). People that adhere to diets that minimize carbohydrates and have high levels of fat show lower percent body fat and better lipid profiles (Zajac et al, 2014). Athletes are able to get a competitive body composition more quickly than when they are on a carbohydrate loading diet. The favorable changes in body composition could contribute to the increased time to exhaustion and increased power output, but it is hard to identify causation. Endurance

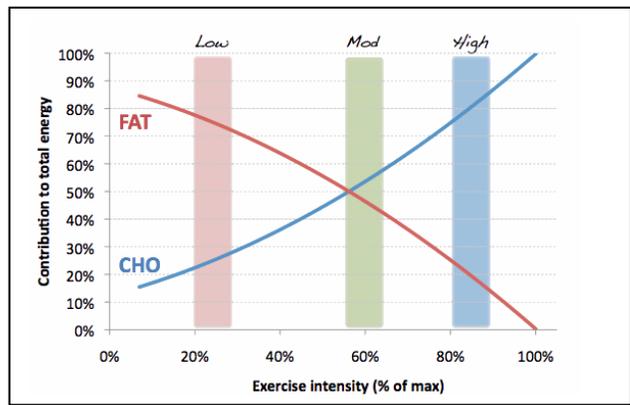


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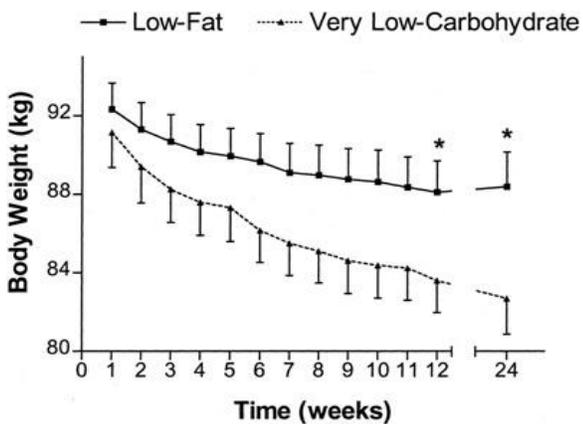
athletes gain a competitive edge when they have less body fat, so that makes this diet option very attractive during training.

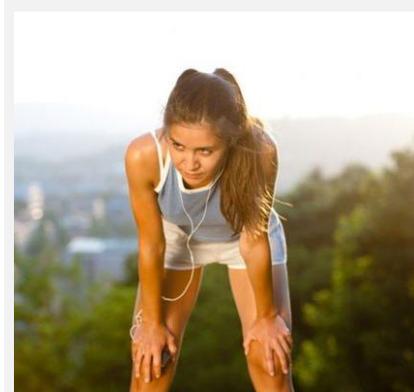
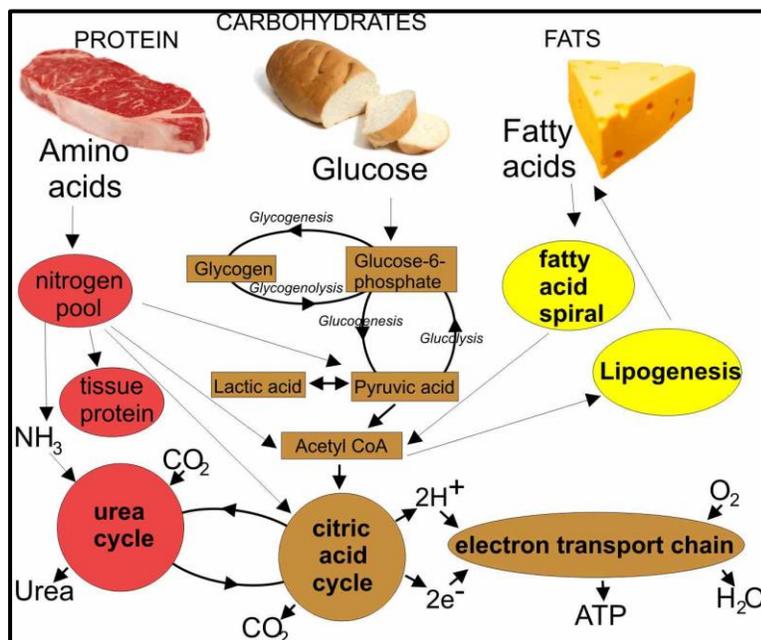
An important note when consuming a high fat diet is to make sure that it contains an adequate amount of calories. The studies analyzed here note that the dietary changes were all isocaloric. Fat has more dense energy at 9 kcals/gram than carbohydrates at 4 kcals/gram, but the recommended calorie intake for an athlete will stay the same no matter what source it comes from. Phinney concludes that the most important factor for performance is that an adequate amount of calories is available for the body to oxidize (2004).

Much of the literature gives a warning that this diet is best suited for training, but not always for competition time. High fat diets are helpful during



the preparation phases because of the changes in body composition and sustained energy for low to moderate intensity exercise that characterizes most training periods (Zajac, 2014). Burke points out that even in endurance competition, athletes often need to have high-intensity capacity to make it up hills, pass competition, or sprint the last leg to the finish line (2007). Those cases require carbohydrate energy to be most successful. There are mixed conclusions in the literature as to how much effect high fat diets have on high-intensity work (70-90% VO₂ max). Although Lambert and Phinney found that there was no statistical difference in high intensity performance between fat or carbohydrate heavy diets, there is more evidence to support that performance is hindered. Burke's study explains that high fat diets down regulate the enzymes that oxidize carbohydrates, so when the body needs quick energy it cannot metabolize it as quickly (2007). Kavouras suggests that a mixed diet is best for competition time for endurance competitors. The balance of fats and carbohydrates will give the athletes fuel to sustain energy for a long time, but will also supply them with quick energy to use during sprints (Kavouras, 2004).





Glucose Sparing Effects

Glucose sparing is a natural response of the body during exercise. To learn more about the mechanisms of this mechanism, [watch this video.](#)

Exercise Metabolism

The body can use fuel from three main sources referred to as macronutrients: carbohydrates, fats, and proteins. Carbohydrates are the body's preferred source of energy because it can be quickly converted to a useable form, starting as glucose and going through metabolic processes to produce ATP. Fat is second most used fuel, and protein is used minimally. The ratio of carbohydrate and fat used as fuel can fluctuate with intensity and duration of exercise, diet, and fitness status of the exerciser.

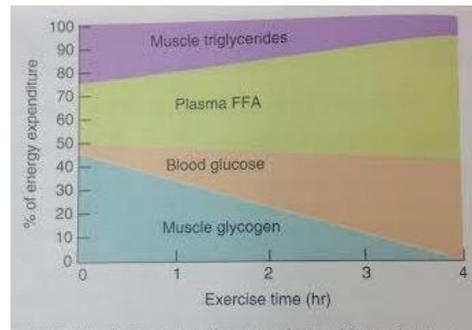
During exercise, the body is naturally in glucose-sparing mode. It will synthesize other stored energy sources to keep the glucose levels in the blood stable. Hormones are the messengers that circulate this message to the body to create a glucose sparing effect. These signals that trigger gluconeogenesis in the liver, block cells from

taking plasma glucose, and cause fatty acids to be broken down in order to preserve glucose. The brain is the only place that does not exhibit glucose sparing because plasma glucose is the form of energy that it uses. Too low of blood glucose levels can cause hypoglycemia, which will cause brain impairment when severe.

When a diet is high in carbohydrates, more carbohydrates are used as fuel because more of it is available. Dieticians hypothesized then that if a diet is high in fat, more fat would be used as fuel, which would save glucose and burn more fat (Cook, 2007). When the fat to carbohydrate ratio is shifted, the enzymes that catalyze breakdown of these nutrients also shift. More fat in a diet will lessen the glycogen breakdown enzymes and increase the fat breakdown enzymes, so more fat is burned during exercise and rest. This was

supported by literature when a lower respiratory exchange rate was observed in athletes on a high fat diet during endurance exercise and rest (Lambert, 1994; Zajac, 2014). A lower exchange rate indicates that the body is using more fat as fuel. The scale is from .7 to 1.0, where a .7 indicates that the body is using all fat and a 1.0 indicates that all fuel is coming from carbohydrates (Howley & Powers, 2012). The fat utilization produces decreased body fat percentage and provides a fuel for the body so glucose can be spared.

Fat is also considered the best fuel for endurance exercise because it has more dense energy per gram than carbohydrate. Fat has nine kilocalories per gram



while carbohydrate has four kilocalories per gram. Energy from fat is stored as triglycerides in adipose tissue as well as other cells of the body as an energy reserve. Fat that is digested can circulate in the plasma as free fatty acids as well. As exercise time increases, more plasma free fatty acids are used as fuel. The body's source of glucose dwindles, and more fat is used to preserve what is left. Because fat in the plasma is increasingly used, it is helpful for endurance athletes to supply it well when they plan on exercising for two hours or more.

The following suggestions are for endurance athletes. They are based on findings from the literature above. Refer to the training diet and competition diet for different suggestions.

Sample Training Diet

Breakfast:

Omelet with vegetables and turkey sausage, fried in butter, apple with peanut butter

Lunch:

Yogurt with blueberries and nuts

Dinner:

Salmon with olive oil, vegetables

Training Suggestions

Taking into account all the pros and cons of a high fat diet, a diet heavy in fats and light on carbohydrates would be helpful during training stages. Whether athletes have dietary restrictions or not, it is beneficial to have a high fat diet while preparing for competition. Training for endurance events often consist of prolonged bouts of lower intensity exercise. Athletes push themselves to go long distances, sometimes even further than the race will require, in order to prepare for competition. When people in training are exercising for long bouts, fat will support them for that prolonged period and help them sustain the work for longer. Because carbohydrates have less than half the amount of energy per gram as fat does, the stores will run out much quicker. The total amount of glycogen stored in a body

Storage Site	CARBOHYDRATE (CHO)		
	Mixed Diet	High-CHO Diet	Low-CHO Diet
Liver glycogen	60 g (240 kcal or 1,005 kJ)	90 g (360 kcal or 1,507 kJ)	<30 g (120 kcal or 502 kJ)
Glucose in blood and extracellular fluid	10 g (40 kcal or 167 kJ)	10 g (40 kcal or 167 kJ)	10 g (40 kcal or 167 kJ)
Muscle glycogen	350 g (1,400 kcal or 5,860 kJ)	600 g (2,400 kcal or 10,046 kJ)	300 g (1,200 kcal or 5,023 kJ)
Storage Site	FAT		
	Mixed Diet		
Adipocytes	14 kg (107,800 kcal or 451,251 kJ)		
Muscle	0.5 kg (3,850 kcal or 16,116 kJ)		

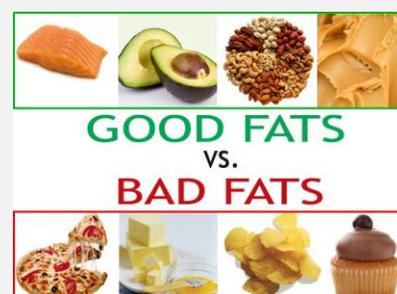
could not sustain more than three hours of cycling on average if that were the only source used. The body would never allow glycogen levels to get that low because of possible brain damage; it has glucose sparing mechanisms to be sure of that. The fat stores on the other hand could sustain activity for much longer because it can contain approximately 111,000 kcals of energy in a healthy individual (Powers & Howley, 2012).

Although fat is not best suited for high intensity exercise, above approximately 70% VO_2 max, the high intensity performance is not as important during training stages. Other considerations should be considered for competition time.

Competition Suggestions

If an athlete participates in competition, they should consider modifying their diet to a mix of carbohydrates and fats. Many races require the competitor to increase their exercise intensity for brief bouts to pass a competitor or make it through a more difficult portion. In order to be ready for those bouts, an athlete should have carbohydrate stored for quick energy use.

For competitors that have a restrictive diet, they can consider consuming fruits and starchy vegetables for carbohydrates. Sport



Sample Competition Diet

Breakfast-

Scrambled eggs, toast with peanut butter, banana

Lunch-

Apple juice, rice, corn, and beans with avocado

Dinner-

Chicken breast, potato with butter, vegetables

Snacks-

Nuts, dried fruit, sports drinks



drinks and juice also provide carbohydrates that are easy to digest and agree with many diets.

It is recommended that 2-3 days before the competition, the athlete should increase their carbohydrate intake to 10-12 g/kg body weight. To ensure that the body can handle carbohydrate intake, it would be best to maintain a mixed diet throughout competition season.

People with restrictive diets can still duel themselves for exercise with strategic diet planning. The biggest concern for this population is consuming enough calories (Cook, 2007)

Sample Meal Plan for Restrictive Diet

This meal plan would fit into the Specific Carbohydrate Diet plan, which limits sugar, grain, and dairy intake. Visit [this website](#) for more details about the diet.

Breakfast:

Egg and black bean burrito with almond flour tortilla, banana, and orange juice

Lunch:

Medjool dates, nuts, salad with chicken and oils

Dinner:

Squash with farmers cheese and tomatoes, meatballs, and almond milk

Snacks:

Fruit smoothie, nuts, almond butter with fruit and vegetables

Implications for a Restrictive Diet

After analyzing the literature, it is clear that athletes can still be competitive while on a low carbohydrate diet. People with health issues that restrict their diet and people wishing to lose weight can gain adequate fuel through fats, proteins, and minimal carbohydrates. Because of the nature of the fuel consumed in those diets, the dieters will have more success with low to moderate intensity (20-60% VO_2 max).

If competition is involved, the dieter will have to find ways to include extra carbohydrates into their diet during competition season. Fruits and vegetables are carbohydrate sources that agree with most diets. Even if sugar is restricted, there are all-natural juice options and drinks like coffee or tea that can act as stimulants.

Life on a Specific Carbohydrate Diet

This family has modified their diet to restrict many carbohydrates after their daughter was diagnosed with Crohn's disease at 15 years old. They adhere to the Specific Carbohydrate Diet (SCD) which has been shown to improve many of the symptoms of gastrointestinal and bowel disorders.

Q: What is Crohn's disease?

A: It is a form of IBD, inflammatory bowel disease; kind of like irritable bowel syndrome. It is an inflammation in the intestines that cause a lot of symptoms like stomach pains, diarrhea, nausea, gas, bloating, and lots of discomfort. It is different for everyone though, I know some people get lots of constipation or even vomiting. My form is ulcerative colitis, so the inflammation is by my colon.

Q: How did you decide to start the Specific Carbohydrate Diet (SCD)?

A: The doctors were having me take a lot of medications, and sometimes they would work but other times they wouldn't. My mom was worried that I had to take so many meds this young, so she did some research on alternative help. She found that SCD had helped a lot of people with Crohn's, so she went to a conference about it. There were a lot of people that felt a lot better and even had improved intestinal conditions from the diet. So even though it is kind of extreme we started it. Now we have been on the SCD for a year and a half!

Q: What does SCD entail?

A: Basically, it cuts out complex carbs, dairy, processed sugar, and most artificial or man-made foods. So we eat lots of vegetables, meat, fruit, and nuts. I can't have any grains, wheat, or starches, which means no breads, noodles, rice, or anything like that. Even if it's considered gluten free we can't have it because it still has complex carbs. Then the no sugar part means we don't have any sugar besides fruit. It's really hard at first! We definitely needed to adjust where we shopped and what we made.

Q: What do you typically eat a lot of now?

A: For breakfast I have a lot of smoothies. We make our own yogurt so it's okay for me to eat, so I have that blended with fruits. For lunch and dinner, I have salads with chicken or nuts on it and we make dressing out of oils. I like making lettuce wraps instead of sandwiches. For meals at home, we usually make a meat and then have steamed vegetables as a side and then fruit for dessert. For snacks I go through different favorites, but it's a lot of cheese, natural peanut butter, Lara Bars, nuts, and dried fruit.

Q: Do you feel like this diet has affected your exercise and sport performance?

A: I play tennis for my school and jog for exercise, so I am fairly active. My dad does the diet with me and he is a lot more active, he does triathlons and is training for that all year. When we first started the diet, we were not used to it so we did not know how to consume enough calories. It is different when the bulk of what you eat is vegetables and fruit; I have to eat a lot more now for the same amount of energy. So in the beginning, I found that I was tired a lot, but once we learned how to make more types of food and eat enough I felt so much better. I think I saw improvement, partially because my Crohn's was under control, partially because I lost weight from being on the diet, and because I was eating healthier. I have more energy now and I have a more muscular body composition. My mom, my dad, and I have lost weight and become leaner. I have made more improvements in my jogging, and tennis is only better because I don't feel sick all the time. The most important thing was making sure I eat enough calories!



Q: Has the SCD relieved your Crohn's symptoms?

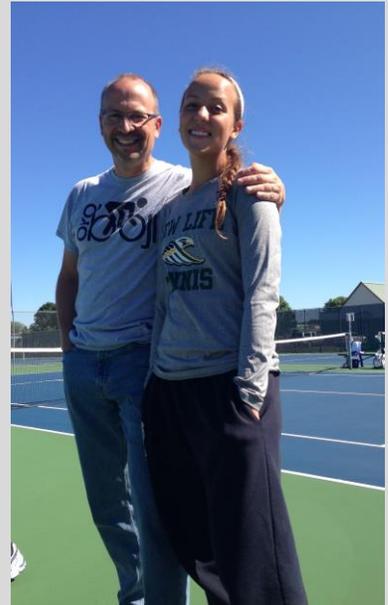
A: Not fully, but I feel a ton better than I did before the diet. When I follow the diet and don't cheat on little things, I feel a lot more energized and normal in day-to-day stuff. I have my appetite back and my digestion has become normal. Every once in a while, things flare up, but it is so much more manageable.

Q: Would you recommend a low or specific carbohydrate to others?

A: Yes! Admittedly, it is really difficult to cut out all the sweets and breads, but I feel better than I have in a long time with this diet. I cheat and have some sweets every once in a while, and I'm still fine, so I'd say if you follow a similar diet at least most of the time you will benefit. If you are struggling with a disease with digestion, definitely look into these diets. Doctors will usually suggest medications and surgeries, and not talk as much about the lifestyle and holistic treatments. It has also really improved my body; I don't have as much extra fat. I'm just leaner than before.

Q: Will you continue the SCD?

A: I will for the near future. I hope to become less strict with it eventually once my digestive tract heals some. It can be tricky to eat at restaurants or friend's houses, so I would like to have a little more flexibility with that. Hopefully within the next years I will be able to do that!



Laurel (daughter) and Dave (father) at a tennis match after one year on the SCD.

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