• TENNIS SPORT SCIENCE REVIEW •

The Effects Of Low-Carbohydrate Fad Diets On The Performance Of Competitive Tennis Play

By Page Love, MS, RDN, LD, CSSD, USPTA with Steve Milano, MSJ, PTR

From media headlines like USA Today's *Pasta Makes You Fat* to best-selling books like *The Atkins Diet* and *The Paleo Diet*, to Novak Djokovic's *Serve to Win* gluten-free diet book, tennis players are often confused about nutrition and drawn into adopting harmful fad low-carbohydrate diets.



Credible science has told us for decades that tennis players, who require muscle energy levels high enough to sustain two or more hours on the court, must eat primarily complex carbohydrates to adequately fuel their training, practices, and competition. Basic physiology and reliable research warn us that in addition to limiting adequate fuel supplies, lowcarbohydrate diets can impair performance and cause health and medical issues that will be presented within this paper.

In terms of weight loss (vs. athletic performance) lowcarbohydrate diets appear to help with weight loss in the short-term because the main source of energy for the body is carbohydrate and without enough carbohydrate energy the body breaks down fat into ketones. Ketones are produced when there is not enough insulin in the body to turn glucose into energy. Thus, the ketones then become the primary source of fuel and energy for the body resulting in weight loss. This is supported by many recent research studies reviewed in the chart below (1, 2, 3, 4, 5). (Table 1)

Table 1.

Authors	Year published	Number of subjects	Study design description	Summary of results
GD Foster	2003	63 people	Low-fat diet group or low- carb diet group	In a yearlong study, completed by Gary D. Foster, the weightloss effect of a conventional diet verses a low-carb Atkins diet on weight loss. Over the course of a year, the Atkins low-carbohydrate diet was not found to be statistically more beneficial than a conventional low-calorie diet. This may be explained by a larger regain of weight in the sample adhering to the low-carbohydrate diet. The data suggests that the weight loss found on the low-carbohydrate diet was most likely not positively affected by the presence of ketones in the subjects' urine.
Samaha FF	2003	132 severely obese individuals	Low-fat diet or low-carb diet	A randomized trial of obese adults, completed by Frederick F. Samaha, found that the group assigned the low- carbohydrate diet lost significantly more weight and displayed greater improvements in triglycerides, insulin sensitivity, fasting blood glucose, and insulin levels on a carbohydrate-restricted diet vs. a low-calorie, low-fat diet. The results are mostly significant for obese adults with a high prevalence of diabetes or metabolic syndrome.

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Authors	Year published	Number of subjects	Study design description	Summary of results
Sondike SB	2003	30 overweight teens	Low-carb and low-fat	Low-carbohydrate diets were shown to help overweight teens lose 2.3 times as much weight as compared to a low-fat diet consumed by the control group in a study run by Dr. Stephen B. Sondike.
Kris Gunnars	2017	23 studies	Low-carb or low- fat diets	A meta-analysis of 23 studies of low- carbohydrate or low-fat diets performed by Kris Gunnars demonstrated that studies of low-carbohydrate diets had a higher statistically significant weight loss when compared to low-fat diets. For many studies, the weight loss was greatest at the beginning and over time weight was regained regardless of whether it was low- carbohydrate or low-fat.
Cara Ebbeling	2018	164 adults age 18- 65 with BMI25+	high, moderate, low-carb diet for 20 weeks.	A study performed on 164 adults, ages 18-65, with an overweight to obese BMI, found that as the carbohydrate content of the test diets decreased, energy expenditure increased during a weightloss phase. This is consistent with a carbohydrate-insulin model and could improve the success of weightloss for obese adults.

Low-carbohydrate diets may be helpful for initial shortterm weight loss, but long-term weight loss may not occur. The above diets reference these results. Harvard's Campos research tracked dieters on low-carbohydrate diets, which revealed that after an initial weight loss (often due to the additional behaviors of dieters such as lower calorie intake and increased exercise) dieters realize no more long-term weight loss than subjects on traditional diets or low-fat diets. (°). Gunners found that subjects trying to lose weight by following a low-carb diet will not see any more long-term weight loss than if they follow a higher-carbohydrate, lower fat diet(°).

This article will explain why low-carbohydrate diets are not appropriate for tennis players, supported by the following:

 Insufficient amount of macronutrients to fuel muscle work during practices and matches;

- Inadequate macro and micronutrients for post-workout recovery;
- · Can promote dehydration and muscle wasting;
- Can lead to long-term health problems unrelated to tennis performance, further degrading workout and match quality;
- Can lead to poor concentration, focus and decisionmaking during practice and matches;
- Can increase risk of early fatigue and possible injury.

This paper will review the nutritional needs of tennis players, discuss how carbohydrates, protein and fat impact tennis practice and play, review the general health problems connected to low-carbohydrate diets, and discuss the shortcomings of specific low-carbohydrate diets for tennis performance.

PHYSICAL DEMAND OF TENNIS

Tennis is an anaerobic sport, characterized by repeated bouts of high-intensity activity (points), followed by longer bouts of recovery, with most points lasting less than 10 seconds. These repeated bouts of high-intensity activity result in muscle work fueled by adenosine triphosphate (ATP) (⁷⁸).

These stores of ATP are only sufficient to assist with muscle contractions for approximately three seconds, or a relatively limited number of muscle contractions. However, as these stores of ATP are quickly burned through during a tennis point, the body produces more ATP for muscle contractions through a series of related chemical reactions, calling on the body's stores of glycogen to produce ATP (*).

After a tennis point, the body begins to replenish ATP stores in the muscles and removes lactic acid and other anabolic waste from muscles. Chu found that tennis players can replace up to 70% of ATP stores within 30 seconds of ending a point (?). However, tennis players must start points within 20 seconds according to ITF rules, and often start points within 10 seconds of the last point ending.

As the intensity of physical activity increases (e.g., moving from a jogging pace to a sprinting pace), the percentage of energy generated from carbohydratesz increases while the percentage from fat decreases. Therefore, during a tennis match, a singles player burns more calories from glycogen (for ATP creation) than fat. (¹⁰)

ENERGY AND MACRONUTRIENT REQUIREMENTS FOR TENNIS PLAY

Caloric needs

Ranchordas has shown that tennis players expend 30-45 kj/ min or 7.5-11 kcal/min in practice. Additionally, this study summarizes reports of total caloric expenditure during match play estimated to be between 649 kcal to 3244 kcal for male players from 60- to 300-minute and for 443 kcal to 1107 kcal for female players from 60- to 150-minute duration matches (¹¹).

At a United States Tennis Association (USTA) camp for female professional players, the women's average recorded three-day food intake was analyzed and found to be 58% carbohydrate, 23% fat and 19% protein, showing that actual intakes of successful tennis players are higher in carbohydrate (¹³).

Carbohydrate

Because of the short point play nature of tennis, most points last less than 10 seconds and require 300-500 bursts of energy over the course of a match. Tennis training and play is anaerobic work which is fueled primarily by carbohydrate coming from glycogen stores. (¹⁰).

In fact, an early study by Bergeron showed that after checking blood glucose levels of elite players during tournament play, researchers concluded that stored glycogen was enough to provide energy for 100 minutes of exercise ⁽¹³⁾.

Because of the highly anaerobic nature of tennis, the latest consensus guidelines from the Academy of Nutrition and Dietetics Consensus Statement on Sport Nutrition recommend that competitive tennis players consume a high-carbohydrate diet between 6-10 g/kg/dy to synthesize adequate muscle glycogen energy stores (¹⁰). These guidelines also recommend that players consume 30 - 60 g/ hr. during matches to maintain energy balance and meet muscle glycogen needs. Players should also consume 11.5 g/kg body weight of carbohydrates within two hours after matches, when glycogen synthesis is highest, to facilitate full replenishment of carbohydrate energy stores (¹⁰).

Considering the research discussed to this point, tennis players should aim for training and match-day caloric intakes of 50-70% of calories coming from carbohydrate food sources. ^(2,4). Love recommends that these can include complex carbohydrate foods such as breads, starchy vegetables, and pastas, as well as fruit and vegetables. In practical terms this means 1-2 cups of complex carbohydrate foods at each meal during the day ⁽²⁾.

Protein

Protein needs for tennis players range from 1.2-2.0 g/kg/day or 10%-20% on training days. Recovery recommendations suggest that consuming .3g/kg after play and strength training and every three to five hours thereafter (¹⁰). In practical terms, most tennis players will need between 3-5 ounces (20-35 grams) of lean proteins in meat form or vegetable protein equivalents such as tofu, beans and meat alternatives, twice per day. Additionally, dairy protein should be consumed in the range of three to four servings per day, such as in the form of milk, yogurt, cheese, etc. (¹³).

Fat

Dietary fat contributes to part of the energy expenditure during tennis workouts and matches, especially in longer matches. One study reported 70% of male players consuming >30 % of total energy per day from fat, so fat needs for male players may be higher than current general sport guidelines (¹⁴).

Conversely, players should be discouraged from consuming less than 20% of their energy from fat as they may not meet their essential fatty acid needs and may suffer from fat deficiency issues such as underweight, fatigue, suppressed hormones and poor recovery and healing (¹⁰).

APPLICATION TO TENNIS PERFORMANCE

The most appropriate calorie intake for tennis players before training and matches is primarily complex carbohydrates. Complex carbohydrate foods should be consumed in meals and snacks in the 1-4 hours before play in a 1-4 g/kg (¹⁰).

During the first hour of activity, Kovacs recommends that tennis players replace lost nutrients by drinking water, then switching to small amounts of carbohydrates, in gels and sports drinks after one hour. This can be accomplished by consuming 30-60 grams of carbohydrate per hour in highercarbohydrate sports food products (¹⁶).

After tennis activity, tennis players should replace depleted glycogen stores, lost water and depleted micronutrients (electrolytes). Carbohydrates are absorbed into to muscles more efficiently if consumed within two hours of activity. The WTA recommends consuming 30 grams of carbohydrates, 15-25 grams of protein and less than 7 grams of fat within 30 minutes to maximize full recovery (¹²). Current guidelines recommend replenishing carbohydrate at a rate of 1-1.2g/kg/hour because the rate of glycogen resynthesis is only 5% per hour (¹⁰).

Protein is essential for muscle repair, and along with complex carbohydrates, is a helpful post-activity nutrient for tennis players. Current research shows varying results supporting both consuming carbohydrate with protein or consuming carbohydrate alone initially after exercise. Similar glycogen repletion rates have been seen with 1.2 g/kg carbohydrate or with .8 grams carbohydrate combined with .4 g/kg of protein during the two hours post training (¹⁰).

Practical examples of carbohydrate/protein combinations for

after-match consumption are chocolate milk and recovery beverages combined with high carbohydrate energy bars, or with a bagel with nut butter or with a peanut butter sandwich with a cup of milk (¹³).

BENEFITS OF HIGHER CARBOHYDRATE DIETS IN ATHLETES

(Table 2) – In making the case for the higher carbohydrate need for athletes, and specifically the tennis athlete, the following studies demonstrate the need for higher carbohydrate intake to enhance performance, improve speed and power, delay fatigue, prevent hypoglycemia, and replenish glycogen (^{11,17,18,19}).

POPULAR LOW-CARB DIETS REVIEWED

Love summarizes a review from Web MD of 11 popular low-carb, high-protein fad diets that demonstrates the lack of proper nutrition, as well as their detrimental impacts on tennis performance (²⁰).

Atkins Diet

The Atkins diet focuses on eating in a way that causes the body to switch from burning carbohydrates to burning fat, called ketosis. This requires eating mostly fat and protein, with a very limited amount of daily carbs in vegetable form. The newest version of Atkins, called Atkins 40, has more relaxed rules, allowing 40 grams of carbohydrates. Critics of the diet point to the higher amounts of animal protein and fat and the long-term increase in blood lipids and increased risk for heart disease. In the initial stages of the four-phase diet, it would be difficult for tennis athletes to meet their energy needs.

Table 2.

Authors	Year published	Number of subjects	Study design description	Summary of results
Mayur K Ranchordas	2013	x	High carb diet	Although tennis is considered an intermittent sport, matches can last upwards of five hours and players must be in peak physical condition in order to perform well. Experts recommend players follow a high-carb diet to delay fatigue and use of a carb supplement during competition.
Wroble KA, Trott MN	2019	16 exercise- trained men and women	4 days of either a low-carb/ ketogenic diet vs. a high carb diet	A recent study comparing the effects of a low-carbohydrate vs. high-carbohydrate diet on exercise found that performance in anaerobic-dependent activities was reduced in participants of the low- carbohydrate diet. Total distance run in the yo-yo intermittent recovery test was 15% lower and peak power was 7% lower in the low-carbohydrate diet. For tennis, a sport with high-intensity, short duration plays in matches that can last hours, a low carbohydrate diet would have "clear performance implications" on athletes especially at the elite level.
Rodrigo V. Gomes	2014	12 young experienced male tennis players	Carb supplement vs. placebo	Tennis matches can last upwards of five hours and consist of high-intensity exercise alternating with short breaks. Due to each match's fast pace, tennis players are often at risk of dehydration, glycogen depletion and hypoglycemia. A five-day study analyzing the effects of CHO supplementation during tennis play found that glycemia levels were better

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Authors	Year published	Number of subjects	Study design description	Summary of results
				maintained and responses were blunted in players that consumed the CHO solution as opposed to the placebo. There was also a slightly lower perceived exertion for these players.
Louise M. Burke	2006	Soccer players	Low-carb diet	Studies indicate that for soccer players with a "mobile playing style", performance can be enhanced with diets that "restore and even super-compensate muscle glycogen levels." One study mentioned by Louise Burke demonstrated that participants on a low-carb diet had a "dramatic reduction" in exercise performance compared to high-carb diet participants. In conclusion, higher-carb diets are recommended for adequately fueling high-intensity intermittent exercise, such as tennis, and restoring glycogen in between sessions.

Brown Fat Revolution (Or carb cycling)

The Brown Fat diet aims to change "bad" yellow fat into "good" brown fat, which is metabolically active and heat producing. It is a four-week diet and exercise program focusing on developing lean muscle, boosting metabolism and building brown fat. The diet alternates between "carb days" and "protein days" and requires eating six times a day, including before and after every workout. Alternating between eating solely proteins and carbs may be a problem for tennis athletes because of the need for both nutrients to stabilize energy levels and to last longer on the court. In addition, diets that require grazing and specific food intake may prove challenging for busy, elite tennis players who travel frequently.

Paleo

The theory of the Paleo diet is that eating a high-protein, high-vegetable fiber diet like cavemen (who were hunters, not farmers), is natural for humans and results in weight loss and maintenance. This diet can be limiting to the tennis athlete because it suggests avoiding complex carbohydrate (almost no starches are allowed on the diet), as well as sodium, the main electrolyte lost in sweat. This diet limits the key nutrients we have described earlier that are critical to tennis play to promote peak performance.

The Protein Power Diet

This low-carb, high-protein eating plan promotes altering our hormonal state by lowering insulin levels, helping our bodies make more glucagon, a hormone with aids in burning fat. The diet provides less than 20% of total calories from carbs or less than 100 grams of carbs per day, although a high vegetable intake is encouraged, recommending 25 grams of fiber every day. For the tennis athlete a limitation of 100 grams of carbohydrate would cause the player to "hit a wall" during longer matches, possibly not having enough energy to finish a match longer than two hours.

South Beach

Written by a cardiologist, this diet is focused on choosing high-quality carbs and fats," emphasizing high-fiber foods. While the low-carbohydrate phase of this diet (the first two weeks) won't provide enough carbohydrates for competitive tennis players, the second phase of this diet is more adequate in high-fiber carbohydrates and more reasonable for many elite tennis athletes to more fully meet their nutritional needs.

Wheat Belly

This diet is a gluten-free eating plan based on eliminating high-glycemic foods such as wheat, barley, rye, spelt, corn, cornstarch, corn syrup, potatoes, legumes and oats. Once you've transitioned off wheat, you may eat limited quantities of other whole grains, such as quinoa, millet, amaranth, and chia, as well as beans. For tennis athletes who rely so heavily on the wide variety of carbohydrate foods that often contain wheat to provide them the building blocks of muscle glycogen, The Wheat Belly diet may leave them lacking in muscle energy.

The Zone

On this diet, participants are encouraged to eat three "Zone meals" and one "Zone snack" each day, comprised of 1/3 protein, 2/3 carbohydrate and only a "dash" of fat. Despite the zone diet allowing more carbohydrate than the previous diets discussed, the plan's calorie restrictions (1,500 **calories** per day for an average male and 1,200 **calories** for an average female) may be the biggest limitation for the tennis athlete who may have caloric demands upwards of a minimum of 3,000 calories per day.

Intermittent Fasting

There are several versions of this type of diet based on alternating days of normal caloric intake with days of lower calorie intake, encouraging skipping of food intake for 24-36 hours at a time. Participators are encouraged to rely on water, coffee or tea to help feel full. Training and playing on fasting days will cause athletes to experience decreased muscle performance and stamina and to experience fatigue, weakness and headaches. In fact, a recent systematic review in 2018 of 11 studies on intermittent fasting weight loss effectiveness showed that there is not greater weight loss results with this diet method vs. a continuous fashion eating plan (¹⁰).

The Ketogenic Diet

The ketogenic diet, a low-carb, high-fat diet, has been successfully used in the treatment of childhood epilepsy for several years, but has recently become a method used for weight loss. Like the Atkins diet, it consists of restricting daily carbohydrate intake which limits the amount of glucose available to tissues to increase fat oxidation.

High-level athletes are beginning to try the ketogenic diet in hopes of increasing their athletic performance. While numerous studies have been done on the ketogenic diet and weight loss, few have been completed on the ketogenic diet and athletic performance. Studies have shown that athletic performance either remained the same or decreased. Athletes also reported negative physiological experiences, including fatigue, especially during the first week of consuming the ketogenic diet. Many of the studies below confirm these negative performance consequences for athletes which allows us to assume that tennis players will suffer the same performance deficits as well. (Table 3) $(^{12,12,33,43,5,50})$.

For tennis players who have weight-management concerns with weight loss being the goal, low-carb diets do not provide any more long-term success than traditional diets. Some of the most credible research on recommended levels of nutrients for weight loss comes from National Weight Loss Control Registry research on dieters who have lost 50 lbs and kept this weight loss off for more than five years. The research shows that the most successful weightloss plans promote very gradual weight loss. The programs average 50-55% carbohydrate, incorporate moderate aerobic activity, involve modifying dining out patterns, and tracking eating patterns (²⁷).

Table 3.

Authors	Year published	Number of subjects	Study design description	Summary of results
Hough, P.	2018	Three male cyclists	Low-carb diet vs. normal diet	Little research has been performed on whether a reduced carb diet (RCD) improves performance. A three-week study on the effect of an RCD diet on three male cyclists showed no improvement in exercise performance. In fact, there were "reports of increased perceived exhaustion" when following the low-carb diet. Participants did report improved dietary habits post- experiment along with decreased body fat.
Shaw, DM., Merien F.	2019	8 male endurance athletes	31-d ketogenic diet vs. regular diet	The team investigated the effect of a 31-day ketogenic diet on submaximal exercise capacity and efficiency. It was concluded that the diet preserved mean submaximal exercise capacity in trained endurance athletes without requiring acute carbohydrate fueling methods. However, there was a greater risk of an endurance decrease at an individual level.
Reagan Barr	×	Athletes	High-quality carbs	Research has shown that carbohydrates are invaluable in fueling the body during performance, especially high-intensity exercise. Although ongoing studies have recognized that athlete's protein needs may be higher than previously thought, carbs should still be the primary source of energy in an athlete's diet.
Chad Cook	2007	1 endurance athlete	Grain-based diet vs. low- carb diet	This case study observed a single endurance athlete after adherence to a grain-based diet versus a low-carb diet. Although no statistical analysis was performed, the athlete had significantly more difficulty during training while adhering to the low-carb diet than the grain- based. He reported feeling lethargic and "untoward physiological outcomes" during performance. This was a subjective analysis.

NUTRIENT DEFICIENCIES AND NEGATIVE HEALTH CONSEQUENCES OF LOW-CARB DIETS FOR TENNIS ACTIVITY

As stated previously, low-carbohydrate diets do not provide tennis players with adequate nutrients for peak tennis performance. Tennis players need high volumes of glycogen for workouts and practices, and the easiest way for the body to generate glycogen is to convert carbohydrates to glycogen. Low-carb diets limit players from meeting their glycogen needs, thus decreasing performance potential. Additionally, tennis players require a greater amount of vitamins and minerals than can be provided by a low-carb diet when compared to a diet high in fruits, vegetables and other carbohydrate-rich foods. Proper hydration is a critical issue for competitive tennis players; low-carb diets can result in dehydration secondary to the process by which the body metabolizes glycogen from muscle. Low-carb diets can also promote muscle wasting or "cannibalization" as glycogen-deprived muscles begin to metabolize muscle tissue to fuel activity.

Low-carbohydrate diets do not provide adequate fuel for intense tennis workouts and matches; additionally, they can create health problems for athletes (as well as nonathletes). Sport dietitians and researchers have summarized the negative impacts of low-carbohydrate diets to athletic performance described below:

- Most high-protein diets are very low in calories, far below the recommended minimums for healthy weight loss without the risk of starving muscle and organ tissue and meeting basal metabolism calorie needs. This low calorie level jeopardizes muscle energy levels and leads to earlier fatigue on the court.
- 2. Most high-protein diets have two to three times the recommended dietary allowance for protein needs (.8 gm/kg protein/BW). This can put the body at increased risk for kidney problems, such as kidney stones and kidney failure earlier in life, as well as increased problems with urinary tract function. For the tennis player, this leads to increased complications with maintaining a normal hydration status and increased risk of heat stress/illness.
- Most high-protein diets are so low in energy and total food variety that it can be challenging to meet recommended dietary allowances for vitamin and mineral requirements without supplementation. Due

to the restricted consumption of fruit and vegetables, antioxidant intake is decreased which can contribute to poor immune function and reduced ability to fight off illness and infection. This can be of extreme concern for the immune system of an athlete, resulting in slower healing and increased risk of injury.

- 4. Most high-protein diets so severely restrict carbohydrate intake, resulting in increased cravings for simple or sugar-type carbohydrate sources which can lead to over-eating later in the day. Eating more of these sugar sources and refined carbohydrate does not improve long-term energy stores for the tennis player.
- Most high-protein diets promote high amounts of water weight loss leading to increased risk of severe dehydration resulting in light-headedness, fatigue, cold sensitivity and decreased metabolic rates. As little as 2% loss of body water can result in decreased performance.
- 6. Most high-protein diets claim that high carbohydrate intake is the cause of America's problem with obesity; however, scientific evidence does not support this theory. Carbohydrates are the body's preferred fuel source for organ and brain function. The body prefers to metabolically use carbohydrates as fuel and will store excesses as fat only when that excess surpasses the daily caloric expenditure needs for that tennis athlete.
- Most high-protein diets are so low in fiber that gut function can be compromised. Prolonged adherence to this type of diet can lead to constipation and an increased risk of colon cancer. Again, the lack of highfiber complex carbohydrate sources will result in low muscle energy stores for the tennis player.
- 8. Most high-protein diets recommend an abundance of animal protein (>10 oz./day), subsequently cholesterol and saturated fai tintake will exceed recommended levels thereby increasing the risk of heart disease. In addition, this can raise uric acid levels and increase the risk of gout and kidney problems, and may lead to gradual weight gain resulting in obesity (²⁹).
- 9. Most high-protein diets accelerate the rate of calcium loss from bone and increase the risk of lowering bone density. High phosphorus intakes from increased meats creates an imbalance that causes an increase in the calcium flux out of bone. For female tennis players, this increases the risk of bone-related injuries such as stress fractures.

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10. Low energy availability can result from low carbohydrate and low-calorie intakes as that seen in the diets reviewed in this article. These issues can additionally lead to menstrual dysfunction and hypo-hormonal imbalances known as a newly named syndrome called REDS – Relative Energy Deficiency in Sport which applies to both male and female tennis players, formerly known as Female Athlete Triad (¹¹).

to meet optimum nutrition and energy needs. Low carbohydrate diets may help with weight loss, but

most likely muscle weight loss will diminish and is not ideal for elite athletes as muscle power and strength will be compromised. Additionally, these diets may have nutritional gaps in vitamins and minerals. Consuming too much protein is not only dangerous to your organs, but also increases the risk of heat illness for the tennis athlete.

tennis athlete extreme dieting is not an appropriate option

A FINAL WORD ON HIGH PROTEIN/ LOW CARBOHYDRATE DIETS

The most common approach to a fad diet is to eliminate major key components of a healthy diet, essentially cutting calories and energy to promote quick weight loss. For the The research presented in this paper testifies to the need for tennis players to adhere to a higher carbohydrate diet to meet energy demands necessary to compete at the highest level for consecutive days, to assist with recovery, and to maintain general health and lower disease risk. Here's to enjoying pasta and rice pre-and post-match!

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ABOUT THE AUTHORS



Page Love

Steve Milano

Page Love is a registered and sport dietitian and certified tennis teaching professional and runs a thriving private practice (Nutrifit, Sport, Therapy) specializing in sport and eating disorders, nutrition in Atlanta, GA. She also serves as a consultant for the international women's professional tennis tour (WTA), men's professional tennis tour (ATP), and serves on the USTA National Sport Science Committee.



Steve Milano is the former executive director of the Professional

Tennis Registry Foundation, where he was editor-in-chief of TennisPro magazine and director of the PTRF International Symposium. He is the executive director of the US High School Tennis Association, as well as a journalist specializing in tennis sport science and general health, fitness and wellness.