METABOLIC EFFICIENCY IN WEIGHT-DEPENDENT ATHLETES

By

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Abstract

Many athletes such as those involved in mixed martial arts (MMA), integrate both strength and endurance activities during training and competition. Carbohydrates are the preferred fuel source during high-intensity exercise. Fat is typically utilized at rest and during sub-maximal exercise. This project was designed to incorporate dietary changes in weight-dependent athletes to attempt to alter substrate utilization at rest. Two female and one male Ultimate Fighting Championship (UFC) fighters were involved in this study. The athletes were tested using indirect calorimetry methods prior to the study. Both resting metabolic rate and respiratory quotient (RQ) were measured. Athletes were provided with a metabolic efficient meal plan based on calorie and macronutrients, and then tested again using indirect calorimetry to discover any changes in percentage of fuel utilization. All athletes' RQ decreased, meaning fat utilization was increased at rest in all athletes. Overall, diet alterations seem to influence substrate utilization at rest. Future research can include body composition and exercise implications on diet alterations in a UFC athlete.

Keywords: metabolic efficiency, substrate utilization, indirect calorimetry, respiratory quotient

Chapter 1 Introduction

Nutrition plays a vital role in overall health in addition to sports training, performance and recovery among athletes. The need for sports dietitians is apparent for many reasons. Athletes seek out strategies that will give them a competitive edge, and nutrition is one of those strategies; however, there is a lack of nutrition knowledge among athletes. A study in 2010 reported only 33.2% of athletes had a basic understanding of sports nutrition (Jessri et al., 2010). Watching and engaging in sports competitions such as the Superbowl and the Olympics are a huge part of societal norms. Athletes, whether elite or recreational, often possess a competitive characteristic and drive that pushes them to want to do their best and win. In addition, athletes want to stay healthy, whether it is avoiding injuries or avoiding getting sick. Nutrition plays a vital role to help athletes stay healthy. A registered dietitian nutritionist (RDN), and more specifically, an RDN that is a Certified Specialist in Sports Dietetics (CSSD), is the most reliable source when it comes to providing sports nutrition education. They are truly the nutrition expert given the number of courses, supervised practice hours, and continuing education credits needed to receive and obtain an RDN credential and a CSSD. Combining these two ideas: a lack of knowledge of nutrition by athletes and their competitive drive, sports dietitians are needed to create a link between nutrition and performance among athletes.

All sports are unique with regards to specific physical tasks and talents by an individual. Different muscle groups are used based on the type of sport. For example, mixed martial arts (MMA) fighters use both strength and endurance during training and performance. Strength is used during high-intensity bouts such as striking or kicking an opponent. Endurance training is used throughout the fight or during times of grappling an opponent where it is lower intensity and more of a steady state type of exercise. Both endurance and strength training require different types of substrate utilization. In other words, different fuel sources are being utilized depending on the level of exercise intensity the athlete will be engaging in.

Measuring the type of fuel that is being burned for energy at the time of the measurement is referred to as the respiratory quotient. The respiratory quotient is obtained from indirect calorimetry and is the ratio of carbon dioxide produced over oxygen consumed. A respiratory quotient closer to 1.00 indicates primarily carbohydrate use for fuel, while a respiratory quotient closer to 0.7 indicates primarily endogenous fat use and lipogenesis (Seebohor, 2014). Recently, this science has been used in athletics as a measure for determining the primary fuel an athlete burns during different types of exercise. This information would be important to an athlete to properly consume foods to meet the demands of the type of fuel they are burning.

Using indirect calorimetry may lead to improved ability to individualize an athletes' diet recommendations. Individualizing an athlete's diet leads to better education and counseling by sports dietitians (Hull et al., 2016). In turn, better education and counseling means more knowledge among athletes in regard to sports nutrition and they are able to incorporate this information into their lifestyle. Better training, performance, and recovery will hopefully be apparent as a long-term effect of individualized dietary recommendations.

Metabolic efficiency is a concept developed by Bob Seebohar, a sports dietitian, who was an athlete himself and was searching for ways to use his energy stores more efficiently (Seebohar, 2014). The concept involves fueling the body in ways to become more of a "fat burner" at rest and a "carb burner" at high intensity exercise (Kerksick et al., 2018 and Farinatti, Castinheiras & Amorim, 2016). To make a certain weight class, an athlete must lose weight (or in rare cases, gain weight). Due to extreme weight loss being difficult on the body, a goal is to gradually lose weight at a steady pace. Becoming metabolically efficient, or a better "fat burner" at rest, can help with body composition (Kerksick et al. 2018). In addition, athletes can save carbohydrate stores for more high intensity exercise, which can improve performance, due to the body's preference for carbohydrates during high intensity exercise. If an athlete is able to keep carbohydrate stores full until high intensity exercise occurs, this may help them perform better and decrease the rate to exhaustion. MMA fighters are both endurance and strength athletes requiring the use of both fat and carbohydrate depending on the type of exercise they are performing at that specific point in time.

Therefore, the research question is as follows: By individualizing diets based on indirect calorimetry, is an athlete able to adapt to utilize a greater percentage of fat as a source of fuel at rest? Objectives include determining athletes' current nutritional status through recall and assessments, analyzing indirect calorimetry data to provide individual recommendations, assessing athletes' understanding and compliance to current recommendations, and remeasuring resting metabolic rate through indirect calorimetry to determine if fat utilization increased at rest.

Limitations

1. RMR data may not be reliable and accurate.
2. There are potential time constraints due to limited athlete availability.
3. Athlete engagement may be an issue due to time constraints and possible lack of interest.

Delimitations

1. The sample size is small and limited to only UFC athletes.

Assumptions

1. Athletes will be honest when providing dietary recall.
2. Athletes are in a fasted state prior to testing.

Definitions

Indirect calorimetry: Measures the type and rate of substrate utilization and energy production through carbon dioxide exhaled and oxygen consumed.

Respiratory Quotient: The ratio of the volume of carbon dioxide exhaled to oxygen consumed.

Sports Dietitian: A registered dietitian specializing in sports nutrition.

Certified Specialist in Sports Dietetics (CSSD): A professional sports nutrition credential that can be earned by registered dietitians.

Metabolic Efficiency: Improving the body's ability to use its energy stores more efficiently.

Metabolic cart: Machine that measures resting energy expenditure and respiratory quotient in a non-invasive way through oxygen consumed and carbon dioxide produced.

Substrate Utilization: Macronutrient usage for energy from rest to high intensity exercise.

Chapter 2 Literature Review

The purpose of this literature review is to examine the current research related to substrate utilization, nutrition timing, current nutrition knowledge among athletes, and recommendations for athletes. According to an article published by Jessri et al. in 2010, college athletes in Iran scored a 33.2% on knowledge related to sports nutrition. Another article from Hull et al., 2016 states that athletes have general nutrition knowledge, but the majority appears to have limited knowledge in regard to nutrition. In addition, athletes seem to have difficulty applying this knowledge into practice and incorporating this into their lifestyle. The *Academy of Nutrition and Dietetics, Dietetics of Canada, and the American College of Sports Medicine* position paper from 2016 states that nutrition plays a vital role training, performance, and recovery. Athletes, whether elite or recreational, possess a competitive characteristic and drive that pushes them to want to do their best and win. Combining these two ideas: a lack of knowledge of nutrition by athletes and their competitive drive, the need for RDN's is apparent to create a link between nutrition and performance among athletes.

With the understanding that there is knowledge deficiency in relation to athletes and nutrition, providing them with the most detailed, customized plan to fit their performance and recovery needs is necessary. The purpose of this literature review is to not only assess athletes' current dietary habits, assess training, performance, and recovery nutrition but also critically analyze the relationship between respiratory quotient, nutritional needs, and athletic performance. Respiratory quotients are commonly used to assess individual performance and diet in pre-training, training, and recovery. By measuring the respiratory quotient, RDN's potentially can individualize a diet through proper nutrition education and counseling and cater to the athlete based on this quantitative data. This, in turn, could aid in better athletic performance due to athletes fueling their bodies correctly.

Substrate utilization during exercise and rest

Carbohydrate, protein, and fat are the three macronutrients ingested from food to use as energy and for metabolic processes in the body. Carbohydrate is the main macronutrient used for energy and is stored in the body as glycogen. Glycogen is broken down into glucose and used as fuel throughout the day, especially by muscles during high intensity exercise. There is fatigue and a reduction in the intensity of sustained exercise when there is glycogen depletion in the body (Thomas, Erdman, & Burke, 2016). According to Tardie (2008) article, *Glycogen Replenishment After Exhaustive Exercise*, glycogen depletion typically occurs after long duration, high intensity training sessions but does depend on each individual, how much glycogen is stored in the body, and the intensity of the workout. Glycogen stores that are at capacity in adults are approximately 450-550 grams of carbohydrate in the muscle and liver (Tardie, 2008). Unless repleted, the athlete may not be able to sustain the activity at a competitive rate for greater than 45 minutes (Gonzalez, Fuchs, Betts, & Loon, 2016). In addition, the brain primarily relies on glucose for fuel and when glucose is depleted, concentration and performance is impaired. In order to promote optimal performance, the athlete should be well-nourished with carbohydrate prior to a high intensity or long duration workout.

Substrate utilization during exercise has been studied extensively throughout the published literature. Spriet (2014) provides insight on the shift in substrate utilization as exercise intensity increases. Fat is the preferred fuel source during low intensity exercise and carbohydrate becomes the primary fuel source as exercise intensity increases. In addition, Spriet

(2014) discusses how free fatty acids are released less frequently from adipose tissue during high intensity exercise.

A recent *International Society of Sports Medicine* review on substrate utilization during exercise states that athletes who are involved in high-intensity training oxidize carbohydrates at a rate of 1-1.1 grams per minute or about 60 grams per hour. Therefore, in order to continue to be able to perform at high-intensity exercise, the athlete must ingest carbohydrate prior to their workout, which is discussed in further detail in pre-training and performance nutrition in this literature review (Kerksick et al., 2018).

The respiratory quotient (RQ) is obtained from indirect calorimetry and is the ratio of carbon dioxide produced over oxygen consumed. Indirect calorimetry is commonly used in a clinical setting when assessing energy balance in critically ill patients. A respiratory quotient closer to 1.00 indicates primarily carbohydrate use for fuel. A respiratory quotient closer to 0.7 indicates primarily endogenous fat use and lipogenesis (McClave, 2003).

Recently, indirect calorimetry has been used in athletics as a measure for determining the primary fuel an athlete burns during different types of exercise. Knowing an athletes RQ during athletic performance would be important to an athlete in that it would inform what foods to consume to meet the demands of the type of fuel they are burning. A study conducted last year by Isomark, LLC for the University of Wisconsin-Madison football team is using an “energy balance” test by measuring the carbon dioxide in exhaled breath. This technology is able to assess the type of fuel an athlete is burning, or the percentage of carbohydrate, protein, and fat (Isomark, 2016). These data show which primary type of fuel each individual player is using for energy during his/her workout. Athletic staff, including RDN’s, are able to enhance performance measures by altering diet and workout routines for maximal performance and health on and off the field. In addition, a company in Italy, Cosmed, is developing similar technology in athletes. The K5 is wearable technology that measures metabolic parameters such as heart rate, energy expenditure, and oxygen consumption (Cosmed, 2016).

General nutrition recommendations

According to the *Journal of the International Society of Sports Medicine* (ISSN) review update energy intake is an imperative consideration when attempting to optimize performance and recovery (Kerksick et al., 2018). The article states that elite athletes need anywhere from 40-150 kcal/kg/day depending on their training schedule and build. In addition, athletes who are most likely to be in an energy deficit can include runners, wrestlers, and boxers, or any athlete trying to lose weight too quickly. Athletes often have busy training and travel schedules which inhibit their ability to eat consistently throughout the day. Therefore, it is important to recommend frequent meals throughout the day in addition to pre and post snacks to optimize training, performance and recovery and avoid inadequate nutrient intake.

Carbohydrate is one macronutrient that is important for optimal performance of an athlete. As the ISSN review mentions, the most important consideration for competitive athletes is carbohydrate intake (Kerksick et al., 2018). Carbohydrate is the preferred fuel source for the body at high intensity exercise. Depending on the type of athlete and their training schedule, however, carbohydrate needs vary per individual.

Protein is also important for athletes engaging in intense training, because….?, Protein needs may be as much as two times the RDA for the average person (1.4-2.0 g/kg/day) (Kerksick et al., 2018). Ingestion of even 3.0 g/kg/day when combined with resistance exercise may have positive effects on body composition as well (Kerksick et al., 2018). If adequate protein is not ingested, there is an increased risk for negative nitrogen balance, indicating protein catabolism and a decrease in muscle mass (Kerksick et al., 2018). Therefore, it is imperative for athletes to consume an adequate amount of protein daily. The best dietary sources of protein include chicken, fish, eggs, beef, and milk due to the complete proteins animal sources provide. In addition, plant sources such as rice and pea protein have shown to be a quality source, although more research needs to be conducted in this area (Kerksick et al., 2018). Fat is another macronutrient important for optimal health and performance among athletes. The ISSN review article states an average of 30% while intake of up to 50% appears to be safe.

Pre-exercise/performance nutrition

Based on what research indicates regarding macronutrients and fuel for the muscles, the timing of meals is important in both training and performance or competitions. Properly fueling the body to optimize glycogen stores, gain energy, and rebuild lean body mass are key components of nutrition for performance. According to Ormsbee, Bach and Baur (2014), timing and composition of meals prior to exercise is imperative. In order to optimize glycogen stores, ingesting carbohydrate prior to exercise is a common practice and studies have shown this improves performance. In Orsmbee, Bach & Baur’s review, the increased glycogen storage prior to exercise is a result of increased ingestion of carbohydrate. Because glycogen stores in the liver decrease significantly overnight, glycogen is most likely depleted prior to a high-intensity exercise in the morning. Interestingly, this review indicated that for exercise longer than 2 hours in the morning, carbohydrate intake prior increased performance measures. However, with exercise lasting less than 2 hours, ingested carbohydrate prior to exercise provided no change. Studies show that carbohydrate ingestion less than 60 minutes before exercise was associated with increased insulin and blood glucose levels immediately before exercise. In regard to effects on performance, most studies show that carbohydrate consumption 2-3 hours prior to exercise is ideal and optimal (Ormsbee, Bach & Baur, 2014).

The type of carbohydrate can also have an effect on performance. According to Ormsbee, Bach & Baur's review, the higher the glycemic index of a carbohydrate, the more rapid the increase in blood glucose. This may decrease fat oxidation with a rapid spike in blood glucose, as many studies have indicated. Therefore, Ormsbee, Bach & Baur (2014), glycogen sparing may occur when a low glycemic carbohydrate is ingested rather than a high glycemic carbohydrate prior to exercise. However, not all studies indicate this but most studies favor on the side of consuming a low glycemic carbohydrate prior to exercise rather than a high glycemic carbohydrate.

Ormsbee, Bach & Baur also mention fat intake prior to exercise. It may be beneficial to ingest fat prior to sub-maximal exercise in order to adapt the body to using this type of fuel and optimize fatty acid oxidation. Reasons for this are to improve body composition in addition to sparing carbohydrate for high-intensity exercise. Consumption of a high-fat meal prior to exercise can help increase free fatty acids in the blood and help increase lipid metabolism and preserve carbohydrate stores during exercise (Ormsbee, Bach & Baur, 2014).

Similar to this concept, Jeukendrup (2017) provides insight on the concept of "training low" and "training high". "Training low" would involve very little carbohydrate stores ingested prior to a steady-state, sub-maximal intensity exercise. Contrary, "training high" would involve ingesting carbohydrate prior to exercise in order to utilize carbohydrate as a fuel source during high intensity exercise. Jeukendrup (2017) refers to some of these concepts as periodized nutrition; altering one's diet depending on the type of exercise or training session they will be engaging in. Another article by Marquet (2016) states a concept known as "sleep low". This implies athletes will be glycogen-depleting during times of sleep. The study showed this did improve performance in subject groups who were engaging in light, endurance activity the following morning. Purdom et al. (2018) shared interesting findings regarding factors that influence fat oxidation. In regard to nutrition, they report high fat diets have recently been shown to increase fatty acid oxidation and positive effects on performance. The authors suggest that consuming a high fat diet helps increase fatty acid oxidation at rest and during low intensity exercise. Alternatively, high carbohydrate diets increase glycogen availability and carbohydrate is the primary fuel source during high intensity exercise (Purdom, et al. 2018).

The literature shows that consuming adequate calories is necessary for performance (NCAA, 2013). As the ISSN review states, it takes about 4 hours for carbohydrate to be digested, absorbed, and stored as glycogen. Therefore, prior to long duration exercise, it may be beneficial to consume a pre-workout meal 4-6 hours before a workout. In addition, a light to moderate carbohydrate snack 30 to 60 minutes prior to high-intensity exercise. 50 grams of carbohydrate in addition to 5 to 10 grams of protein is optimal to increase the availability of amino acids, decrease catabolism, and minimize muscle damage (Kerksick et el., 2018). In addition, the review mentions carbohydrate and protein intake is particularly important for weight-dependent athletes. It is also important for athletes to ingest glucose/electrolyte solutions for exercise that last longer than 90 minutes.

The role of the sports dietitian is to consider these pathways and optimize performance for an athlete by providing them with the necessary education and counseling in regard to food sources, macronutrient amounts, and timing of meals. The typical “one size fits all” approach is no longer relevant or appropriate. In order for a sports dietitian to individualize a diet plan for an athlete, it is imperative for them to understand the type of fuel an athlete burns and caloric expenditure during different types of exercise. Ways to do this are to use biomarker methods such as the respiratory quotient.

Post-exercise/performance nutrition

Consuming adequate nutrition post-training or performance is imperative for athletes' recovery and overall health. According to Ivy (2013), stored fuel is used during exercise and must be replenished after in order for tissue damage to be repaired and adaptations to be initiated. Ivy (2013) recommends 1.2 g/kg/body weight per day. Protein should be consumed immediately post exercise and at frequent intervals, such as every 30 minutes if exercise intensity is high. If an athlete is consuming less than this amount, the addition of protein may be helpful in upregulating glycogen synthesis. Providing the proper fuel for recovery is necessary to restore the muscle glycogen after it is depleted (Thomas, Erdman, & Burke, 2016). Exercise, in particular resistance training, causes muscle protein to be broken down. Dietary protein intake can play a vital role in rebuilding tissues and healing during this process

Additionally, Alghannam, Gonzalez & Betts (2018) also agree with a co-ingestion of protein and carbohydrate following exercise. Due to glycogen depletion being a main factor in athletes' fatigue at high intensity exercise, it is helpful to replenish glycogen stores post-exercise. These authors state that one potential way to accelerate the rate of muscle glycogen synthesis is to co-ingest with added protein. 1.2 g/kg/body weight of carbohydrate can help maximize muscle glycogen repletion if there is repeated exercise shortly after. If carbohydrate is sub-optimal (less than 0.8 g/kg/body weight) ingestion of 0.3-0.4 g/kg/body weight of protein may be helpful in order to accelerate this process.

The type of carbohydrate intake that Algannham, Gonzalez, & Betts (2018) mentioned in their review article for post-exercise would be a high-glycemic carbohydrate such as fructose or sucrose to help replenish glycogen stores more quickly. For timing purposes, several studies indicate it is best to consume carbohydrate and protein immediately post-exercise, as the longer an athlete waits to consume food post-exercise, the less glucose uptake could occur in the body (Algannham, Gonzalez & Betts, 2018).

Rustad et al. (2016) conducted primary research on the co-ingestion of carbohydrate and protein following exhaustive cycling. This study demonstrated an improvement in performance following a intake of carbohydrate and protein within 2 hours post-exercise the day before. A placebo-controlled study involved eight trained cyclists and supplemented 1.2 g/kg/body weight of carbohydrate and 0.4 g/kg/body weight of protein following exercise. Subjects performed cycling the next day and the cyclists who ingested both carbohydrate and protein together had significantly better results than the placebo group who only consumed carbohydrate post-exercise.

There is limited research in regard to dietary fat intake post-exercise. Several studies indicate carbohydrate and protein is the best fuel source to enhance muscle recovery and restore glycogen. These studies and reviews are mostly involved with high-intensity and long duration exercise but do indicate the amount of carbohydrate and protein for maximal glycogen replenishment.

Carbohydrate and protein should be consumed within 30 minutes following intense exercise and a high carbohydrate meal should be consumed within 2 hours following exercise (Kerksick et al., 2018). This helps restore glycogen and promote an anabolic hormonal effect, but the type of meal and amount of carbohydrate consumed should be individualized based on the athlete’s needs. However, Coletta, Thompson and Raynor (2013) shared their findings on carbohydrate and carbohydrate-protein supplements on endurance running for recreational athletes. They found that additional research is needed on the topic as no significant differences were found among the carbohydrate and carbohydrate-protein group, or the carbohydrate group compared to the placebo. The authors stated their limitations included a homogeneous sample, self-reported diet and exercise prior to the study. This study did not find carbohydrate during exercise hinders performance.

For muscle protein synthesis (MPS), the ISSN review article discusses the need for protein ingestion before and/or after resistance exercise. Although the time period depends on the athlete’s tolerance, it is important to have protein as soon as possible after a workout for the anabolic effects. In addition, having protein throughout the day and every 3-4 hours is optimal according to Kerksick et al. (2018).

As most of the research suggests, post-exercise nutrition is imperative as well. Areta et al. (2013) discuss the importance of a ~20g bolus of protein following exercise provide a “maximal anabolic stimulus”. The results were inconclusive on a longer recovery period (12 hours), therefore amplifying the importance of ingesting protein in a shorter time frame following exercise. The ISSN review on nutrient timing found the importance of both carbohydrate and protein ingestion following exercise to replenish glycogen stores and increase muscle protein synthesis. Not only is the timing important (as soon as possible post-exercise) but the type of nutrient (carbohydrate and protein) for overall recovery. The findings from Schoenfeld, Aragon, and Krieger (2013) suggest that protein timing in fact does not have an effect on muscular repair and remodeling. However, until more research is conducted in this area, ingesting protein soon after a workout will not cause negative results.

Interestingly, more research is being conducted in the area of high-fat, low-carbohydrate diets. One concept of “train low, compete high” has been gaining popularity. This is where the athlete follows a high-fat, low-carbohydrate diet for 1-3 weeks before re-introducing carbohydrates back into the diet. Overall, the ISSN review states that although ketogenic diet has increased in popularity, there is inconclusive evidence as to whether this type of fueling strategy has a positive effect on performance. In some studies, the ketogenic diet may improve exercise endurance by training the body to burn more fat during this type of exercise, while other types of studies show this does not have an effect on performance. Other studies show this a high-fat, low-carbohydrate diet may help improve body composition by decreasing body fat (Kerksick et al., 2018).

Overall, this can have major implications for weight-dependent athletes. Improving body composition and decreasing body fat percentage can potentially make it easier for an athlete to reach his or her weight goals. Particularly for combat sports, an athlete needs to spare carbohydrate for high intensity work, such as striking. Endurance and lower intensity is also relevant during competition, therefore ideally fat could be used as a substrate at this point in time.

Metabolic efficiency concept

In order for an athlete to perform at their highest potential, an athlete’s eating patterns and overall nutrition becomes an essential part of their life. Metabolic efficiency is a concept developed by Bob Seebohar, a sports dietitian, who was an athlete himself and was searching for ways to use his energy stores more efficiently (Seebohar, 2014). The concept involves fueling the body in ways to become more of a “fat burner” at rest and a “carb burner” at high intensity exercise. Seebohar discusses the “Metabolic Efficiency Point” (MEP) where there is a crossover point during exercise. Carbohydrate and fat burning intersect and carbohydrate becomes the dominate fuel source as exercise intensity increases. Seebohar states there are enough carbohydrate stores to support 2-3 hours of moderate intense exercise. He believes an athlete should fuel the body with carbohydrate prior to exercise in order to adapt the body to use this type of fuel. In his book, *Metabolic Efficiency Training: Teaching the Body to Burn More Fat*, respiratory quotient is thoroughly discussed and is described as the type of fuel someone is burning at rest. Several other literature supports this concert as well. Purdom, Kravitz, Dokladny, & Mermier (2018), discuss factors that effect maximal fat oxidation. Training status, intensity, duration and nutrition can all effect fatty acid oxidation. In relation to nutrition, diets that have higher proportions of fat to carbohydrate have been shown to support this concept. High fat diets decrease glycogen content in the muscle. On the other hand, high carbohydrate diets increase glycogen in the muscle (Purdom, Kravitz, Doklaldny & Mermier, 2018). Limitations to strictly high fat diets include the inability to perform at high intensity exercise due to the fast glycolytic action, meaning the body predominantly uses carbohydrate during this time (Purdom, Kravitz, Doklaldny & Mermier, 2018). In addition, high fat diets have also been shown to lower RQ both at rest and during moderate intensity exercise.

Cameron-Smith et al. (2017) found similar results related to metabolic efficiency and similar concepts. 14 male cyclists and triathletes consumed either a high carbohydrate diet or a high fat diet of similar energy content for 5 days. Resting muscle and blood samples were taken at baseline on day 1 and again on day 5. This study concluded that fatty acids may have a significant role in gene expression. Genes necessary for fatty acid transport and oxidation are expressed in abundance in the high-fat group. Fatty acid oxidation was 7-fold greater than the high-carbohydrate group. Authors state this may have strong implications to oxidize fat at a greater extent but there research at high intensities should be studied in this regard (Cameron-Smith et al., 2017).

Marquet et al. (2016) introduces the concept of “sleep low” where glycogen stores remain low during a period of rest in order to adapt the body to better utilize fat at rest. 11 trained cyclists were put into two groups over a period of one week. One group was involved with carbohydrate periodization and implemented the “sleep low” concept and the control group consumed consistent carbohydrate throughout the day. A 2-hour sub-maximal endurance test was conducted which indicated the “sleep low” group improved their performance (+3.2% compared to control). An increase in pacing occurred in the “sleep low” group compared to the control. Overall, the authors concluded this could have positive implications on performance in endurance athletes (Marquet et al., 2016).

Specifically related to nutrition plans, there are several metabolic efficient nutrition strategies Seebohar references in his book. The first is carbohydrate to protein ratios. He believes 1:1 ratio of carbohydrate to protein grams is ideal for performance and recovery. This should be used throughout most meals during the day. A 2:1 can be used before or after a workout that is longer than 2 hours. A 3:1 should be used after a 3-4 hour workout or very high intensity that lasts longer than 90 minutes. Lastly, a 4:1 ratio should rarely be used. Seebohor’s next concept is periodization plates, which is a concept referring to the type of exercise the athlete is engaging in and what their plate should consist of. For example, during competition, an athlete should ingest whole grains, but out of competition an athlete should have very little whole grains on their plate. Another concept includes carbohydrate restoration, which is where the athlete refuels with carbohydrate sources in order to restore glycogen. Seebohar advises athletes to not follow carbohydrate restoration for longer than one day, especially if some of the exercise is of lower intensity. Overall, Seebohor’s concept of metabolic efficiency is training the body to burn fat at rest and use carbohydrate at higher intensity exercise. As years progress, it is assumed there will probably be more research and interest in this area.

There are many similarities and differences between Seebohor's concepts and the *Academy of Nutrition and Dietetics (AND), Dietitians of Canada (DC), and the American College of Sports Medicine (ACSM)* position paper (2016). Similar to Seebohor's concepts, the position paper discusses consumption of both carbohydrate and protein (20-30 grams) post-recovery to lead to protein and glycogen synthesis and improved nitrogen balance. The academies gave this an evidence grade of "Grade 1- Good" (Thomas, Erdman, & Burke, 2016).

In relation to carbohydrate consumption for maximal carbohydrate oxidation during exercise, there is limited evidence on the subject (Grade III). However, the paper mentions the oxidation conditions were greater in glucose and glucose+fructose as compared to water placebo. This supports Seebohor's ideas in relation to consumption of a carbohydrate source prior to exercise to enhance carbohydrate oxidation. Low glycemic choices may be beneficial for long duration activity when carbohydrate cannot be ingested during exercise (Thomas, Erdman, & Burke, 2016).1-4 g/kg consumed 1-4 hours prior to exercise is optimal for pre-event fueling. In support of Seebohor's theory, training with limited carbohydrate availability inhibits the ability to perform at high-intensity exercise (Thomas, Erdman, & Burke, 2016). However, there is also limited research on this topic (Grade II- fair).

According to the position paper, nutrition periodization is essential and must be individualized to the athlete based on training schedules and individual needs and goals (Thomas, Erdman, & Burke, 2016). A high-fat, low carbohydrate diet can be maintained to promote fatty acid oxidation, but this can only match the exercise intensity. In other words, the athlete is unable to perform at high intensity exercises if glycogen stores are depleted and fat is the primary fuel source. However, further research is warranted on the topic (Thomas, Erdman, & Burke, 2016).

Athlete nutrition knowledge, current dietary habits and access to RDN

It is important to assess an athlete's current dietary habits to understand a relative baseline of what the typical athlete is consuming on a daily basis. Some may be very familiar with nutrient periodization and pre and post fueling strategies while others may have very limited knowledge in the subject.

A study by Coutinho et al., in 2016 evaluated dietary intake among pentathlon athletes. Fencing, swimming, equestrian jumping, and a combined event of pistol shooting and running all make up a pentathlon in Brazil. Dietary intakes among athletes are often low in calcium and iron, and high in saturated fats. The authors stated, "young athletes constitute a population that is vulnerable to the physiological effects of chronic physical fatigue owing to intense exercise, especially if they have inadequate food consumption" (Coutinho et al., 2016). The study was comprised of 56 athletic volunteers who were between 10 and 18 years of age and healthy. Biochemical profile, energy expenditure, food and supplements were all assessed. Food records were evaluated using a 24-hour recall method and food-frequency questionnaire. Energy expenditure was measured by days of the week with the most calories burned on Wednesdays and Saturdays. 62% of athletes reported using some type of nutritional supplement, most prescribed by their trainer. 86% of athletes had not received any nutritional counseling. The results showed that dietary intake among athletes was very high in fish and processed meats, however, this was once a week or less. Legumes were consumed by 95% of athletes 5 times a week or more in addition to 43% eating baked goods and 30% consuming soft drinks 5 times a week or more. Results indicated few pentathletes are eating fruits and vegetables in addition to inadequate energy, carbohydrates, vitamin A and C, and calcium. The authors suggested that consuming small snacks could help meet the athlete's energy and nutrient needs. They also mentioned that athletes receive unreliable information in regard to supplements, so therefore, having a nutrition professional on staff or to consult with may be beneficial. Overall, athletes had inaduate eating habits such as low fruit and vegetable intake and high consumption of soft drinks. In addition, the athletes frequently engaged in supplement use without consulting with an RDN (Coutinho et al., 2016).

In elite Australian rugby players, 46 male athletes' nutrition knowledge was assessed in a study by Devlin & Belski (2015). The athletes answered 123 questions related to nutrition knowledge, dietary recommendations, sources of nutrients, choosing everyday foods, alcohol, and sports nutrition. The mean nutrition knowledge score was 60.5%. The majority of the athletes answered questions related to increase of fruit and vegetable consumption correctly and to decrease fat intake. Most of the athletes were, however, unable to provide sources of unsaturated fats. Overall, this study concluded that there are deficits in nutrition knowledge among elite male Australian rugby players (Devlin & Belski, 2015).

Nutrition practices have been studied among NCAA Division III football players as well in a study by Abbey, Wright, & Kirkpatrick (2017). Of the 88 participants, greater than 50% reported consuming starches/grains, meat and dairy daily on a questionnaire. However, less than 50% reported consuming fruits and vegetables daily (Abbey, Wright, & Kirkpatrick, 2017). In addition, most athletes reported dining out about 2.5 times per week, with approximately 71% of those restaurants being fast food.

Overall, athletes' current dietary habits tend to be poor based on limited evidence. There are limited studies on the dietary practices of athletes particularly related to mixed martial arts

(MMA). Ideally, more studies will be conducted for this population as the importance of maintaining and making weight are imperative to the sport and whether or not an athlete is able to compete.

Role and effectiveness of RDN in athletics

The sports RDN is involved in several roles in regard to athletes. They are responsible for assessment of nutrition needs and current dietary practices, interpretation of test results, formulating dietary prescription and education, collaborating and integration with other team members, and evaluation and professionalism (Thomas, Erdman, & Burke, 2016). The RDN must gather information related to training schedules and dietary habits and assess any nutrition-related health concerns such as eating disorders, food allergies and supplementation use. They must be able to understand and interpret test results related to body composition and other anthropometric data. Based on these results, dietary prescriptions must be formulated to support training demands and ensure adequate nutrition among the athletes. Dietary prescriptions can include timing, quantity and quality of food sources. The RDN is part of a multi-disciplinary team and must contribute and collaborate to ensure the highest quality healthcare for the athlete (Thomas, Erdman, & Burke, 2016).

According to an article in the *Journal of the International Society of Sports Nutrition*, access to an RDN influence dietary habits among athletes (Hull et al., 2016). Unfortunately, most college athletic departments have a limited budget to staff a sports dietitian. Division II and III schools are even more restricted with their budget. Sports dietitians represent only 5.4% of the NCAA staff members throughout all of the schools throughout the United States. The study by Hull et al. (2016) also examined the dietary intake among athletes who had a full-time sports dietitian verses those athletic teams who did not. A cross-sectional survey design was used to look at dietary habits. Several questions were asked to a variety of NCAA Division I athletes in a variety of sports. Questions included sport participation, general eating habits, breakfast, hydration, nutritional supplements, post-workout nutrition, and demographic information. Seeing an RDN once a month for four months significantly improved dietary knowledge and dietary intake. Athletes who did not have a full time RD on staff received nutritional advice from strength coaches or athletic trainers. Dietitian delivered nutrition education once a month for four months to NCAA Division I volleyball athletes resulted in improvements in energy and macronutrient intake, in addition to overall nutrition knowledge (Hull et al., 2016). Interestingly, athletes who used a sports dietitian were about 49% less likely to consume fast food prior to a practice or competition, indicating a sports dietitian may have some effect on an athlete's food choices. Overall, authors concluded that working with an RDN improved overall nutrition knowledge and dietary behaviors.

In another study conducted by Spronk, Heaney, Prvan & O'Conner (2015), they concluded that elite athletes who had previous dietary education had better nutrition knowledge than those athletes who did not (61.6% vs. 56.6%). This study involved 101 elite Australian athletes from a variety of team sports. Overall, higher nutrition knowledge and female gender were positively associated with better diet quality. The mean nutrition knowledge score was 55.2%. The athletes who had previous education in the area of nutrition had significantly higher results than those who did not (71.2% vs. 53.6%).

An additional article published in 2011 by Oliver et al. studied the effectiveness of dietary intervention in male athletes participating in resistance training. A dietitian assessed, counseled, and educated eleven male athletes. The male athletes were provided a supplement post-workout. In addition, diet records were obtained before the study, then at week 3, 7, and 11.

Results determined nutritional counseling did not change the energy intake by athletes pre and post study. However, protein intake was much greater from baseline to the end of the study. Carbohydrate intake decreased as well. There was also a significant increase in lean body mass, but no significant effect on body fat percentage (Oliver et al., 2011). Although the authors stated the need to be fueled properly through adequate carbohydrate intake, the recommendations these dietitians provided were relatively lower in carbohydrate and very high in protein. Therefore, this study exemplified athletes' compliance to dietary recommendations from an RD. The author's main conclusion was that compliance among athletes could be positively affected by having an RD on staff and providing education.

A similar study published in 2015 researched whether nutritional knowledge translated into practice among athletes (Alauynte, 2015). The subjects were professional Rugby players with the reasoning that the physiological demands of the sport means a higher need for proper fueling for training, performance, and recovery. Previous research has shown not only is there inadequate knowledge of nutrition but also poor diets as well. Research also suggests Rugby players tend to focus less on their diet than other endurance athletes, hence why they are the subjects for this study. The study included thirty male Rugby players from the UK, 18 to 34 years of age. The players were provided a nutritional questionnaire, which had 28 questions and asked about advice, and current recommendations they are given, food group classification, and food choices. There was also a food frequency questionnaire provided. The results showed a nutritional knowledge average of 73%, which is relatively high compared to other studies. However, these athletes were considerably older than previous studies, had higher levels of education, and were considered professional athletes. The authors concluded that an increase in nutritional knowledge such as fruit and vegetables may improve the likelihood of an athlete consuming fruits and vegetables. In addition, providing resources in the area of nutrition to elite athletes may be helpful in aiding in overall diet quality (Alauynte, 2015).

It is apparent that there is a need for sports dietitians and that athletes are more likely to be knowledgeable and comply with dietary recommendations from an RD on staff. However, it may be possible to provide better education and counseling among athletes by individualizing diets through indirect calorimetry.

Tools to help RDN's individualize care and recommendations for athletes

An article published by Volek (2016) studied the effect of high or low carbohydrate diets and peak fat oxidation in a cross-sectional study. The purpose of this study was to assess dietary intake and the effect macronutrients have on the type of fuel burned during exercise. The authors wanted to test the difference between high and low carbohydrate diets by using FASTER (Fat Adapted Substrate Trained Elite Runners) to compare metabolic differences. They compared male ultra-endurance runners which are men who run longer than 26 miles. Ages ranged from 21 to 45 years old and competition continued for two consecutive days; 10 men who consumed a high carbohydrate diet and 10 men who consumed a low carbohydrate diet. Participants who adopted a diet for 6 months or longer and ate greater than 55% of daily calories from carbohydrate were considered in the high carbohydrate group and those who ate less than 20% of calories from carbohydrate were in the low carbohydrate group. The subjects were tested for their maximal aerobic capacity by breath-by-breath gas exchange measurements every 30 seconds for as long as 18 minutes until the subjects stopped the treadmill. After baseline measurements, subjects consumed a shake (either high or low carbohydrate). Subjects moved to the treadmill and ran at an intensity of 64% of their VO2 max for 180 minutes. Blood was obtained during and immediately after exercise to test for glucose and triglyceride levels. Indirect calorimetry measurements were taken at 30, 60 and 120- minutes post-exercise. T-tests were used during statistical analysis to test for differences between high carbohydrate and low carbohydrate groups. When comparing high versus low carbohydrate groups, there was no significant difference in aerobic capacity. Peak fat oxidation was 2.3 times higher in the low carbohydrate group. In addition, respiratory exchange ratio (RER) patterns were significantly lower in the low carbohydrate group than the high carbohydrate group. The RER is the ratio between the amounts of carbon dioxide produced to the amount of oxygen consumed. Interestingly, there were no differences between the rates of glycogen utilization among exercise for both groups. The author's main conclusions were a high-fat, low carbohydrate diet results in high rates of fat oxidation, but glycogen utilization and repletion patterns were similar between groups.

This study was one of the first to demonstrate the association between long-term high fat/low carbohydrate diets and the ability to oxidize fat more effectively. This study shows that an athletes' current diet can have an effect on fat utilization, but this study was unable to conclude changes in glycogen utilization. The *Academy of Nutrition and Dietetics* position paper stated that properly fueling the body with carbohydrate does indeed have an effect on glycogen utilization (AND, 2016). Based on the Volek study, the main idea for a dietitian to consider would be in relation to an athletes' current intake playing a role in the type of fuel burned. The type of exercise can have an effect as well.

Strengths of this study include multiple factors being measured during the trial in order to receive a complete depiction of metabolic components. In addition, this study was the first to examine long-term consumption of a high or low carbohydrate diet and demonstrates the ability to oxidize fat at several different intensities. As mentioned above, weaknesses pertain to the low participants in the study and a prospective study design over a cross-sectional design would be helpful in this case. By utilizing this data and similar studies, sports dietitians are better capable of generating a diet based on fuel sources being used due to common dietary patterns. A dietitian can individualize and adjust current dietary intake to help shift the RQ higher or lower; to burn primarily fat, primarily carbohydrate, or a combination of both.

In another study using the RQ, the association between substrate utilization and muscle mass was evaluated in a cross-sectional sample (Farinatti, 2016). Using two different types of exercise, a leg press (LP) and a chest fly (CF), the authors examined the amount of muscle mass and the influence on energy expenditure and substrate utilization during exercise on 10 male volunteers. Data was assessed on four consecutive days. Resting VO2, RER, and load corresponding to a 15-repitition max was tested. A standard meal was provided the day of the test to minimize metabolic effects of nutritional intake (240 kcal (38 g of carbohydrate, 8 g of fat, and 4 g of protein), respectively. RER, VO2 and VE were measured during exercise and post-exercise. ANOVA was used to find differences between RER, carbohydrate and fat consumption. Key findings include the VO2 during exercise was higher (7.36 ± 1.10 vs. 4.73 ± 0.99) in the LP than the CF. The RER was also higher in the LP than CF. The authors concluded that larger muscle mass caused a higher VO2 than smaller muscle mass. Lipid oxidation occurred after both exercises. Fat oxidation is greater after resistance exercise performed with larger muscle mass. The study used many measurements for greater accuracy and to decrease error such as a standardize caloric and food intake, the same exercises for every individual, and a similar sample size related to experience with resistance training. To strengthen and gain a better understanding of this topic, a similar study may be conducted using larger sample size and more past history data on the participants. Knowing this information, a dietitian may be able to account for the different types of exercise performed by an athlete and generate a nutritional diet plan based off these results. For example, a heavy weightlifter verses a primarily marathon runner may be using different types of fuel utilization during their exercise routine. Distinguishing between mostly fat oxidation or carbohydrate utilization during exercise segments, a diet may can be geared toward fueling the body due to what it uses for energy.

A study in the *Journal of the International Society of Sports Medicine* by Wingfield et al in 2014 studied the effect of exercise and nutrition on respiratory exchange ratio in women. This study examined the effects that food intake has on respiratory exchange ratio and whether they burn more carbohydrate or fat based on their dietary intake. Active women (n=20) participated in this study. They completed six exercise sessions including a variety of different workouts such as aerobic endurance, high-intensity resistance training, and interval running. They also had two nutritional interventions including 25 grams of carbohydrate and protein both before exercise. RER was determined using indirect calorimetry at baseline, immediately post-workout, and 30 and 60 minutes post exercise. The RER was significantly higher from high-intensity interval training than aerobic training. This indicates that more carbohydrate was being used as fuel during high-intensity interval training than aerobic exercise (Wingfield et al, 2014). Authors concluded that protein ingestion prior to exercise increased fat utilization, and consuming carbohydrate prior to exercise increased carbohydrate utilization during exercise. Overall, body composition may improve if protein is ingested prior to exercise as opposed to carbohydrate for high-intensity work (Wingfield et al., 2014).

A study also published in the *Journal of the International Society of Sports Nutrition* looked at macronutrient intake on fuel utilization and potential sex differences (Mock, Hirsch, Roelofs, Trezler, & Smith-Ryan, 2015). As these authors mention, evidence has shown that women oxidize more fat for fuel at rest than males do. Lower carbohydrate intake has an association with a lower respiratory exchange ratio, which studies have shown may improve aerobic endurance. There were 28 active college-aged volunteers in this study. They were asked to complete a three-day food record and logs were analyzed using the Food Processor program. RER was analyzed using indirect calorimetry on a cycle ergometer. The cycling test was 6 minutes long and the RER was assessed every minute. For men, the results indicated a positive association between carbohydrate intake and an increase in RER. Women had a higher RER compared to men during high-intensity exercise and there was also a positive correlation between RER and protein intake. Interestingly, this was the opposite for men. Ideally, the ability to oxidize fat will be beneficial for long-term aerobic events instead of using carbohydrate stores. The authors concluded that further studies were needed on the basis of long-term effects of dietary intake and fuel utilization.

Summary and Conclusions

As literature shows, it is important for a diet plan to be individualized according to the type of sport or exercise the athlete will engage in. A power lifter may have completely different nutrition recommendations to those who are marathon runners as both duration and intensity levels vary completely.

As technology improves, there are a variety of ways to test substrate utilization at rest. Using indirect calorimetry and measuring the respiratory quotient, sports dietitians and sports scientists are able to assess the percentage of each macronutrient an athlete uses at rest.

In conclusion, research over the past several years has led to this concept of metabolic efficiency. The concept involves fueling the body with the type of substrate depending on exercise intensity. As exercise intensity increases, carbohydrate is the primary fuel source.

Therefore, prior to high intensity exercise, the body should be fueled with carbohydrate and protein. To replenish glycogen stores, carbohydrate and protein can be beneficial post-exercise. Otherwise, fat can be used as the primary fuel source at rest and for sub-maximal exercise. Overall, the athlete can benefit from protein consumption throughout the day in order to repair muscle damage and may improve body composition.

Generally, both collegiate and elite athletes have limited knowledge in regard to nutrition. However, studies have shown if an athlete has previous education from a sports dietitian, this may help nutrition knowledge, overall dietary habits, and ultimately, athletic performance.

Therefore, the purpose of this literature review was to evaluate current dietary habits among athletes, assessing the effectiveness of sports dietitians, and understand substrate utilization both at rest and during exercise. By understanding these concepts and using proper indirect calorimetry technology, a sports dietitian may be able to create individual diet plans to improve the respiratory quotient at rest for athletes. This, in turn, may improve body composition and possibly spare carbohydrate use for high intensity exercise. This may be particularly useful and beneficial for weight-dependent athletes, such as those involved in combat sports.

Chapter 3 Methods

Substrate utilization during exercise has been studied extensively throughout the published literature. The purpose of this research project was to assess whether an athlete may become more efficient at burning fat at rest after individualized dietary recommendations. Ideally, these recommendations will be adopted into the athletes' everyday lifestyle for positive outcomes related to training, performance, recovery, and overall health.

Study Design

This was a pilot study to examine metabolic efficiency before and after individualized dietary recommendations. Indirect calorimetry was measured initially at the beginning of the study and again four to six weeks later after athletes were given a meal plan based on their initial indirect calorimetry results and nutrition assessment. Two of the three athletes were provided with all meals and snacks at the UFC Performance Institute and the third athlete lived out of state and was responsible for his own meals and snacks.

Subjects

Three subjects were chosen based on availability over the course of several weeks. Two of the three subjects were living in the Las Vegas area during the time of the project, while the third subject came for testing but lived out of state. Two subjects were female, one was male. The first subject was a 28-year old female of Indonesian descent, weighing 121 pounds. The second subject was a 34-year old male of German nationality, weighing 201 pounds. Lastly, the third subject was a 25-year old female of Mexican decent, weighing 132 pounds. All subjects were generally healthy individuals currently out of competition, with no scheduled fights during the study, and with no pertinent medical history.

Diet prescriptions

Prior to the study, the dietitian was responsible for assessing current dietary habits among the 3 subjects. Athlete 1 overall incorporated a well-balanced diet. She ate 3 meals per day with snacks, primarily consisting of a variety of protein, carbohydrates, fat and fruits and vegetables. She typically consumed food before and after workouts, although was not informed prior to the study on proper macronutrient distribution before and after training. Athlete 2 was the male remote athlete whose diet typically involved high carbohydrate and high fat options. This athlete ate out at restaurants quite often and reported inconsistency in his meals and calorie intake. Athlete 3 had a diet consisting of primarily ethnic foods; reporting a lot of starchy carbohydrates such as white rice and potatoes. This athlete was not educated in regard to consuming foods pre and post workout.

Diet prescriptions for each athlete were made for three certain scenarios; a double high-intensity training day, a high intensity followed by a low intensity training day, and a rest day. The resting metabolic rate was calculated using indirect calorimetry. The two female athletes were on a weight maintenance plan. Therefore, the rest day calories were calculated using results from indirect calorimetry. For double high-intensity days, and the high-low intensity days, the Harris-Benedict equation was used with corresponding activity factors. “Extra active” (very hard exercise & physical job or 2x training) for high-high intensity days, and “very active” (hard exercise/sports 6-7 days a week) for high-low intensity days. The male athlete was on a weight loss plan of 1-2 pounds per week, therefore calories were decreased by 500 calories per day to reach a goal of at least 1 pound of weight loss per week.

Meals and snacks plate graphics were made using excel (Figure A-C). After researching the concept of “training high” and “training low”, an athlete was provided with a meal plan in the calorie goal range catered to that athlete. Primarily starchy carbohydrates (such as sweet potato, brown rice, quinoa, starch-dense powders) and protein were provided prior to training at high intensity. If an athlete was at rest or engaging in low intensity exercise, an athlete was provided with primarily fat, protein, and vegetables throughout the day. In order to replenish glycogen before another high intensity training session, an athlete would be provided with a high-glycemic carbohydrate source after their morning exercise session. The focus of the meal plan was to ensure workouts were "bookended", meaning an athlete was being fueled with the proper substrate prior to the level of intensity the workout. Also, providing fuel after a workout for muscle recovery and to replenish some glycogen stores that may have been lost during that workout.

All nutrients were provided in a similar way to the diabetic exchange system. All nutrients counted for exchanges. For example, approximately 20-25 grams of carbohydrate is one carbohydrate serving. For protein, 1 serving is 12-14 grams and a fat serving is 7-8 grams. Dietitians were available to answer questions related to the exchange system and clarify any confusion related to the topic.

Protein (1 serving – 12-14 grams)	Fat (1 serving – 7-8 grams)	Starches (1 serving – 20 -25 grams)	F/V (1 Serving)
2 oz Chicken or ½ Cup Chicken salad	2 tsp oil/butter (coconut, olive, avocado, etc.)	½ Cup Brown/Wild rice cooked	1 cup Berries or ½ Cup Raspberries
2 oz Beef/Steak	1.5 Tbsp Pesto	½ Cup Quinoa cooked	½ Banana
2 oz Turkey/Deli Turkey	1 Tbsp Nut butter (peanut, almond, cashew)	½ Cup Farro cooked	1 Cup Pineapple/mango
2 oz Pork	½ Small Avocado	½ Cup Couscous cooked	1/3 Cup Dried fruit
2 oz Salmon/Mahi Mahi/Cod	¼ Cup Hummus	½ Cup Cooked oatmeal/farina/porridge/grits	2 Cup Leafy greens (spinach, chard, kale, collard greens, romaine, arugula etc.)
2 oz Tuna or ½ Cup Tuna salad	1 Tbsp Nuts (Almond, peanut, cashew, walnuts, pecans, etc.)	½ Cup Whole wheat pasta cooked	1 Cup Roasted veggies
2 oz Lamb	2 Tbsp Salad dressing	½ Cup Garbanzo, kidney, black, lima, etc beans and lentils (also contains protein)	1 Cup Fresh veggies (tomatoes, mushrooms, onions, carrots, cucumbers)
2 eggs	2 Tbsp seeds (chia, flax, hemp, sunflower, etc)	½ Cup Mashed potatoes	1 Cup Beets
1.5 cups milk or 1 Cup Fairlife milk	1 Tbsp Chimichurri	Medium size sweet potato/potato	1 Medium size apple
2 Slices Cheese	7 Olives	½ Cup Peas, corn	1 Medium size pear, peach, etc.
2/3 Cup Greek yogurt (5-6 oz) or ½ Cup Cottage cheese	2 Tbsp Tapenade (olive, pepper, dried tomatoes)	1 Slice whole wheat bread	1 Cup Cruciferous veggies fresh or cooked (brussels sprouts, cabbage, broccoli, cauliflower)
1 Veggie Burger (12-14 gr protein/per)	2- 3 Tbsp Babaganoush	6 " Tortilla	1 Cup green beans
1 Turkey/Lean beef burger	2 tsp Mayo or Aioli	1 Sandwich Thins	1 Cup of Cauliflower rice

UFC PERFORMANCE INSTITUTE Table 1. UFC Performance Institute Macronutrient Guide

The RMR was necessary to assess daily energy expenditure and providing a balanced meal plan or a deficit for the weight loss athlete. The initial baseline indirect calorimetry results of RQ affected the meal plan regarding carbohydrate intake. For example, an athlete who primarily burned fat at rest prior to the study was able to incorporate carbohydrates more than an athlete who was primarily a carbohydrate burner. In other words, the dietitians were more aggressive with the meal plan regarding metabolic efficiency concepts for those athletes who burned primarily carbohydrate at rest. In those situations of an athlete who is already primarily a "fat burner" the goal of this study was to examine if the athlete was able to utilize an even greater percentage of fat at rest as opposed to baseline.

Two of the three athletes were provided with meals and snacks at the UFC cafeteria. The dietitian ordered the meals for the athletes. The athletes had a choice on what they would like to order, as long as it was compliant with their macronutrient exchanges. These two athletes were provided with all snacks at the UFC PI as well. On weekends, the athletes were occasionally provided with *Trifecta* meals as the cafeteria was closed on the weekends. The athlete who was remote, was provided with check-ins via phone or email a few times during the study. See *dietary compliance* section for information regarding compliance.

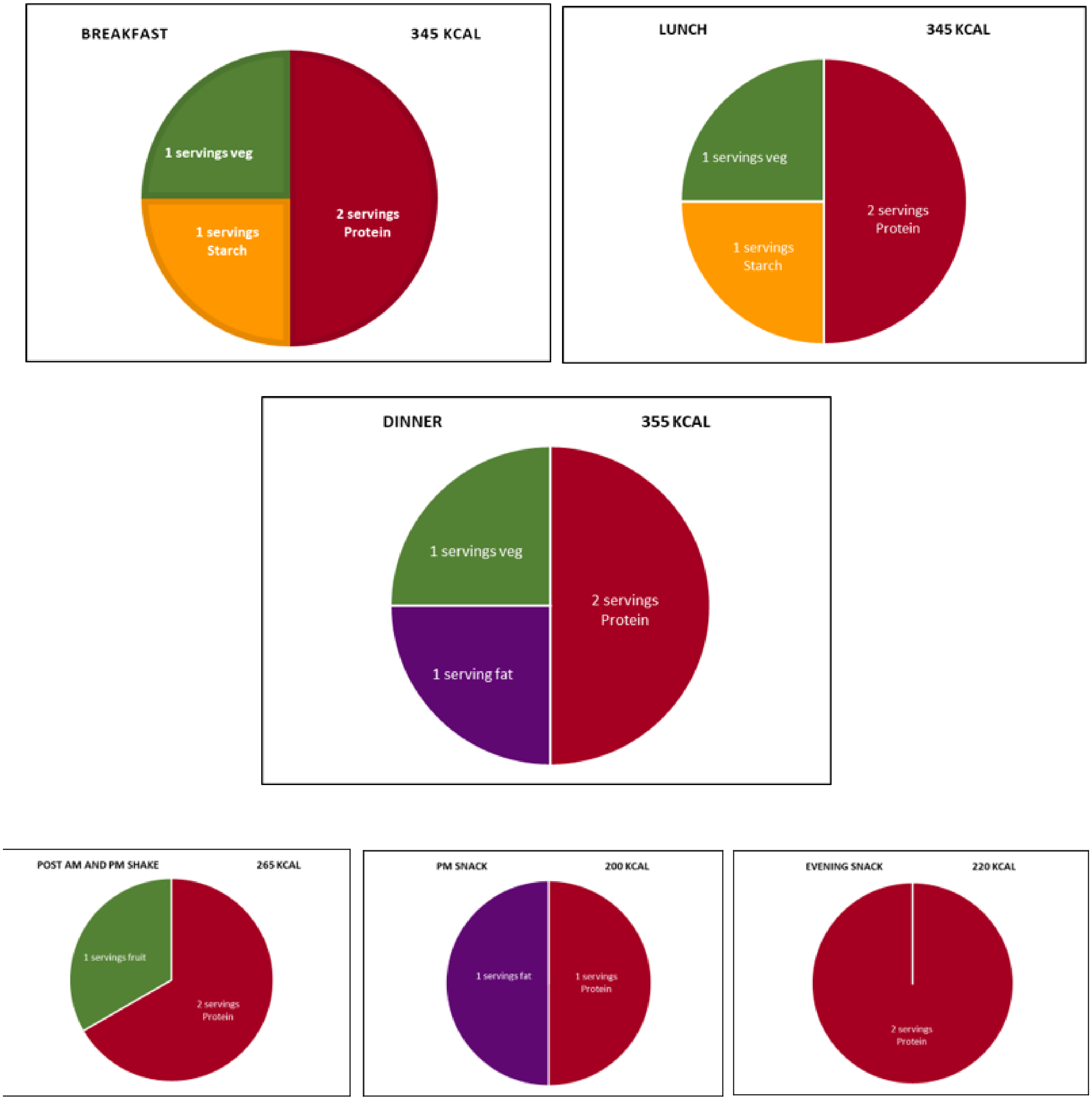


Figure A. Sample meal plan: high-high intensity day

Red: Protein
Green: Fruit or veg
Orange: Starch
Purple: Fat

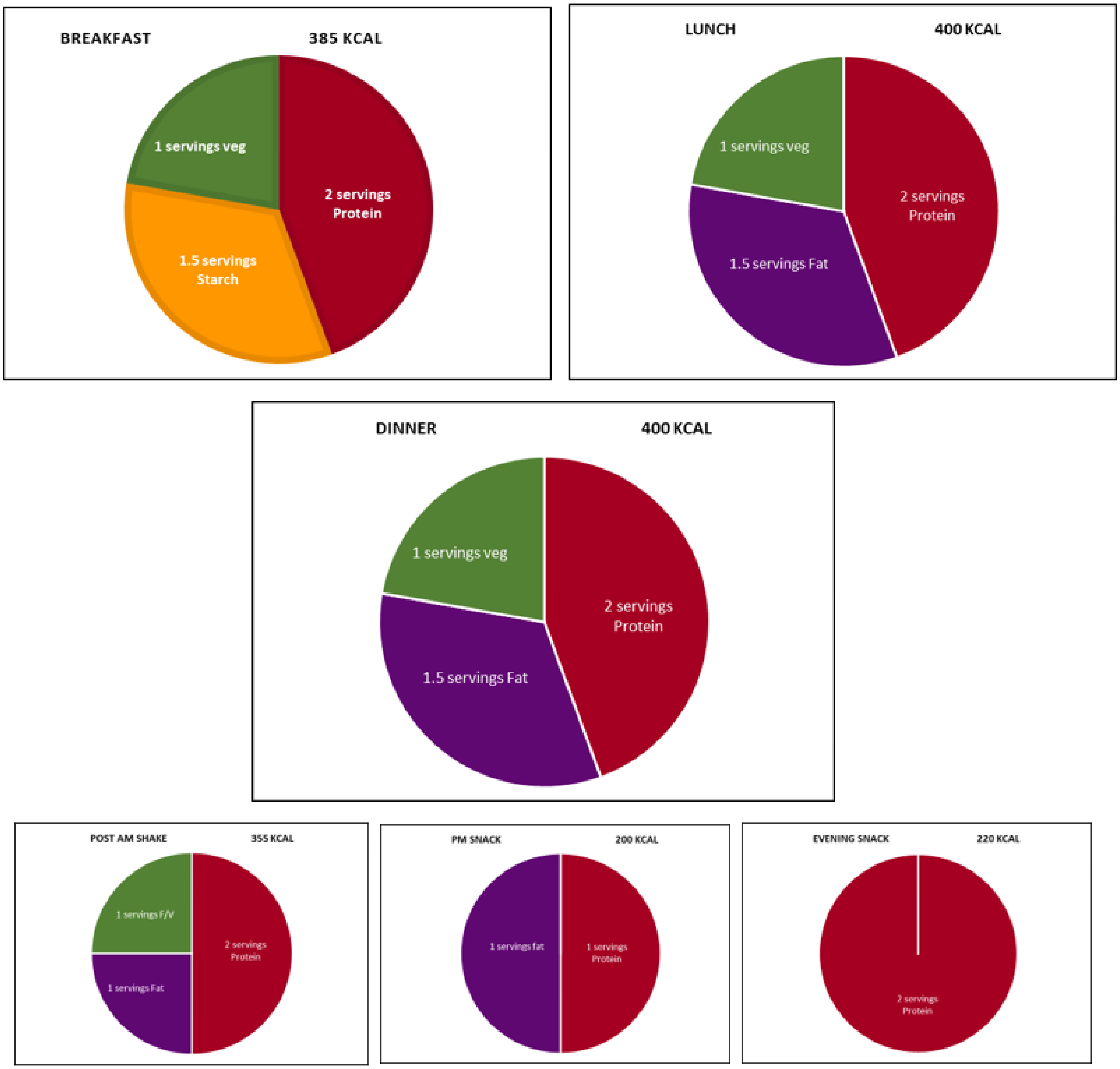


Figure B. Sample meal plan: high-low intensity day

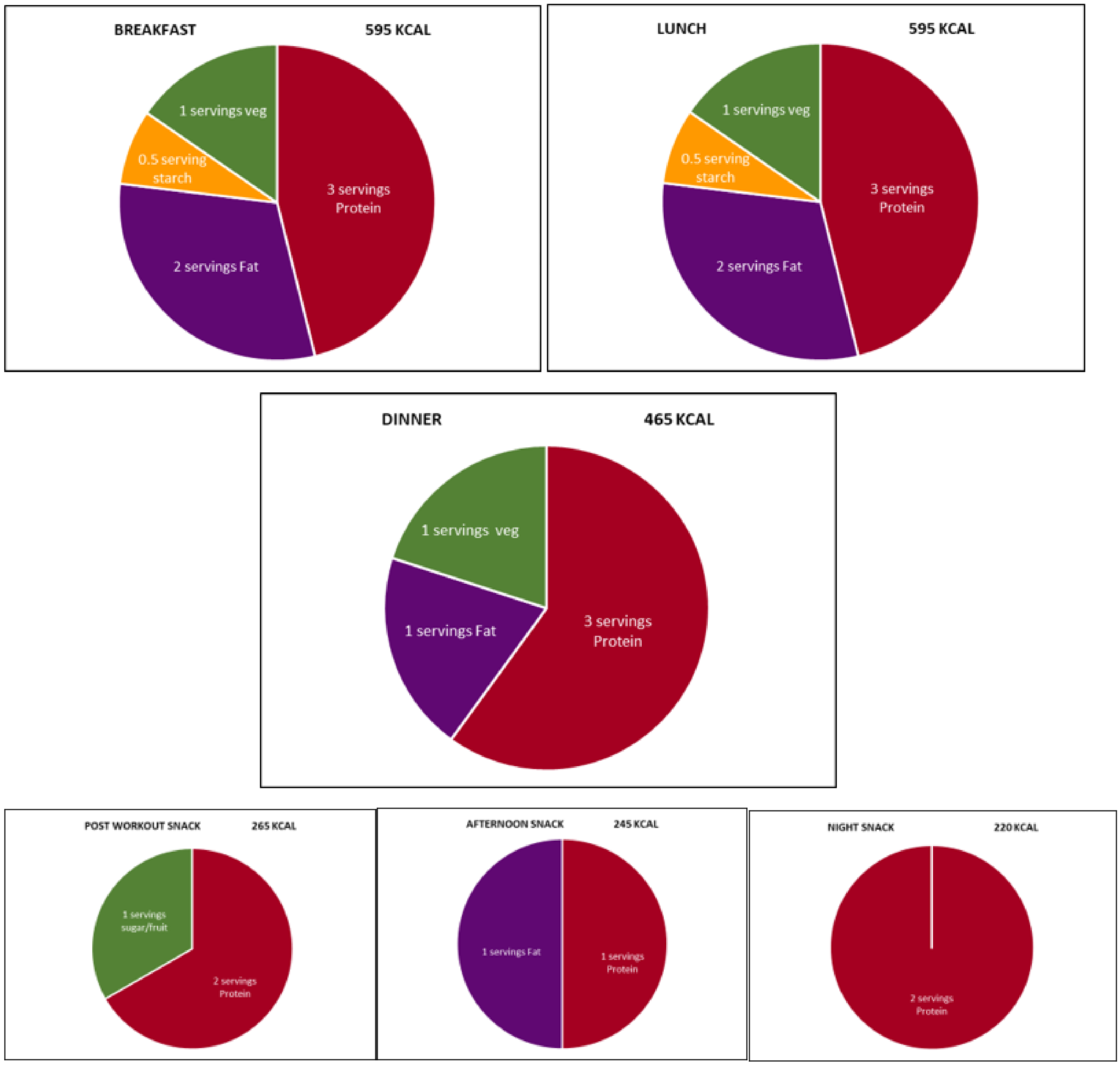


Figure C. Sample meal plan: low/rest day

	High-High Intensity	High-Low Intensity
8:00am	Breakfast	Breakfast
9:00am	Strength and Conditioning- 1.5 hrs	Strength and Conditioning- 1.5 hrs
10:30am	Post-workout shake	Post-workout shake
11:00am		
12:00pm	Lunch	Lunch
1:00pm		
2:00pm	High intensity sparring session- 2 hrs	Low intensity wrestling session- 2 hrs
3:00pm		
4:00pm	Post-workout shake	Post-workout shake
5:00pm	Snack	Snack
6:00pm		
7:00pm	Dinner	Dinner
8:00pm		
9:00pm	Snack	Snack

Figure D. Sample schedule for high-high and high-low intensity days.

Data Collection

Athletes met with the UFC PI nutrition staff, all of whom were Registered Dietitians, for an assessment of typical training schedule and dietary recall. Indirect calorimetry was assessed using RMR, to which testing lasted roughly 30 minutes. This data in addition to the recall of the athletes' daily dietary habits were used to make individual recommendations for each athlete during a meeting either later that day or within 2 days of initial testing. Examples of recommendations included consuming starch-dense carbohydrates prior to a high-intensity session or consuming a fat-rich food source before a low-intensity session. (*See diet prescription above*). A 20-30 minute discussion with the athlete involved dietary recommendations and the reasoning behind it. Short-term substrate utilization outcomes at rest were measured rather than long-term outcomes due to time constraints. The dietitian/intern met with the athlete again approximately four to six weeks later to re-test RMR.

RMR Testing

For the RMR procedure, the metabolic cart (Cortex), using Metalyzer 3B, was calibrated properly by allowing 30 minutes for the Metalyzer to warm up. Sensor adjustment and ambient air was calibrated in MetaSoft Studio according to protocol. The athlete profile was found in the system and weight was updated. Athletes were fasted without any food and limited water for 12 hours prior to the test. A heart rate monitor was placed on the athlete in addition to a mask in order to measure oxygen consumption. The athlete laid down was told to not move or talk during the test. After the dietitian clicks “start”, the test ran for 30 minutes with periodic checks on the athlete to ensure proper data collection. Once the test was complete, the instructor clicked on “stop test” and “next”. In order to ensure a resting state, the time interval average is changed to 60 seconds. The test is then complete. Once the tests were completed, all data was saved in OneDrive in PDF format. This data was then used to assess substrate utilization at rest.

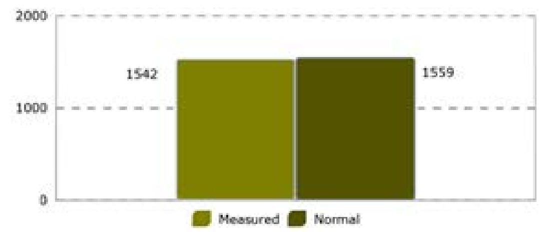
Dietary compliance

Two of the three athletes lived in Las Vegas, while one was remotely consulted. After hours, the athletes reported being compliant with their meal plan and consuming foods that fit into their exchanges for that particular meal or snack. Sometimes the athletes would consume Trifecta on weekends, otherwise reported being compliant with meals they made or bought themselves. The athlete who was remote, reported occasionally having “cheat days”, but being compliant about 90% of the time.

Chapter 4 Results

Each of the three subjects were tested using indirect calorimetry. At baseline, Athlete 1 (female) burned approximately 35 kilocalories (kcals) per hour of fat at rest and 26 kcals per hour of carbohydrate at rest (Figure 1).

RMR	**1542 kcal/d**
Normal	1559 kcal/d
RMR/Weight	25.7 kcal/d/kg
RMR/BSA	930 kcal/d/m2
Deviation Normal	-1 %



Variable	Unit	Value
V'O2	L/min	0.22
V'CO2	L/min	0.18
RQ		0.82
RMR/kg	kcal/d/kg	25.7
RMR/BSA	kcal/d/m2	930
CHO	g/d	154
FAT	g/d	90
PRO	g/d	18
EECHO	kcal/h	26
EEFAT	kcal/h	35
EEPRO	kcal/h	3

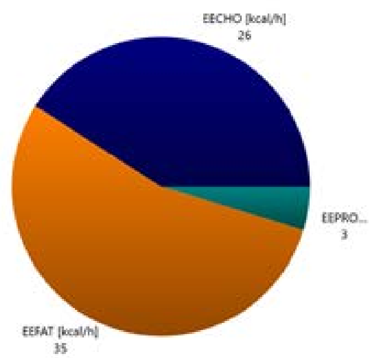
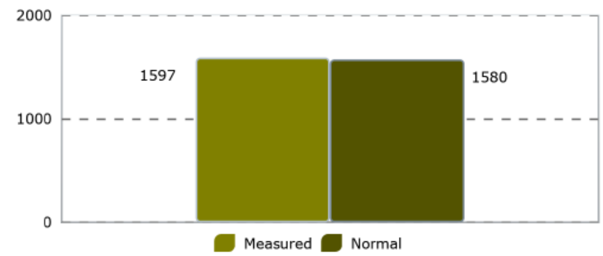


Figure 1A. Athlete 1 pre-meal plan data

RMR	**1597 kcal/d**
Normal	1580 kcal/d
RMR/Weight	25.8 kcal/d/kg
RMR/BSA	950 kcal/d/m2
Deviation Normal	+1 %



Variable	Unit	Value
V'O2	L/min	0.23
V'CO2	L/min	0.18
RQ		0.78
RMR/kg	kcal/d/kg	25.8
RMR/BSA	kcal/d/m2	950
CHO	g/d	102
FAT	g/d	119
PRO	g/d	18
EECHO	kcal/h	17
EEFAT	kcal/h	46
EEPRO	kcal/h	3

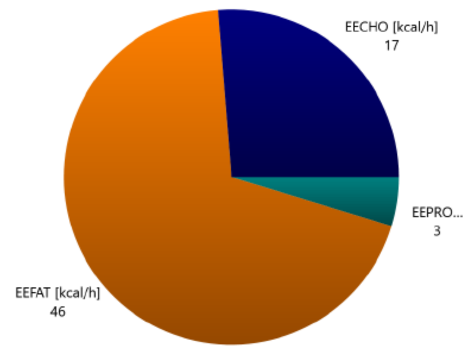


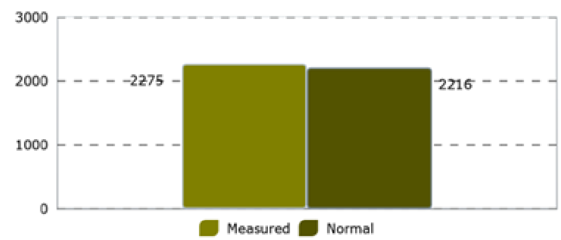
Figure 1B. Athlete 1 post-meal plan data

This athlete burned more fat than carbohydrate as a fuel source at rest prior to the study. Several weeks after the athlete was provided with a meal plan (such as the sample listed above in Figures 1A and 1B) and was presumably following it, RMR testing was conducted again. The athlete burned approximately 46 kcals per hour of fat and 17 kcals per hour of carbohydrate. Fat oxidation increased at rest over the course of several weeks for this athlete. Interestingly, this athlete's average kcal burned per day increased over the course of the study.

Athlete 2 (male) burned approximately 65 kcals per hour of carbohydrate and 25 kcals per hour of fat prior to the study. This athlete burned more carbohydrate than fat at rest. For the second RMR measured weeks later, the athlete burned roughly 51 kcals per hour of carbohydrate and 34 kcals per hour of fat. Although the athlete burned less carbohydrate and more fat at rest post-study, carbohydrate continued to be the primary fuel source for this athlete at rest. The average amount of kcals burned per day decreased for this athlete over the course of the study as he was on a weight loss plan, which may be expected with increased weight loss and possibly lower caloric intake per day over the few weeks of the study.

Results

RMR	**2275 kcal/d**
Normal	2216 kcal/d
RMR/Weight	23.8 kcal/d/kg
RMR/BSA	1090 kcal/d/m2
Deviation Normal	+3 %



Variable	Unit	Value
V'O2	L/min	0.32
V'CO2	L/min	0.29
RQ		0.91
RMR/kg	kcal/d/kg	23.8
RMR/BSA	kcal/d/m2	1090
CHO	g/d	381
FAT	g/d	65
PRO	g/d	25
EECHO	kcal/h	65
EEFAT	kcal/h	25
EEPRO	kcal/h	4

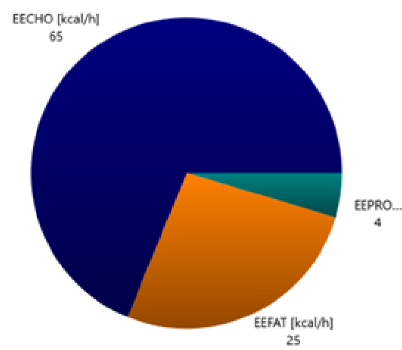
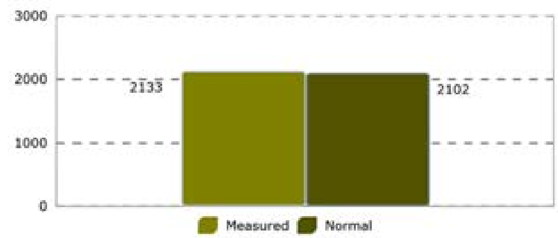


Figure 2A. Athlete 2 pre-meal plan data

Results

RMR	**2133 kcal/d**
Normal	2102 kcal/d
RMR/Weight	24.2 kcal/d/kg
RMR/BSA	1058 kcal/d/m2
Deviation Normal	+1 %



Variable	Unit	Value
V'O2	L/min	0.30
V'CO2	L/min	0.26
RQ		0.87
RMR/kg	kcal/d/kg	24.2
RMR/BSA	kcal/d/m2	1058
CHO	g/d	296
FAT	g/d	88
PRO	g/d	24
EECHO	kcal/h	51
EEFAT	kcal/h	34
EEPRO	kcal/h	4

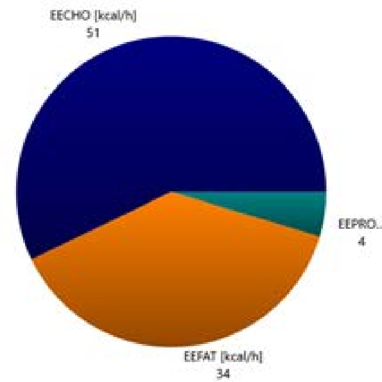
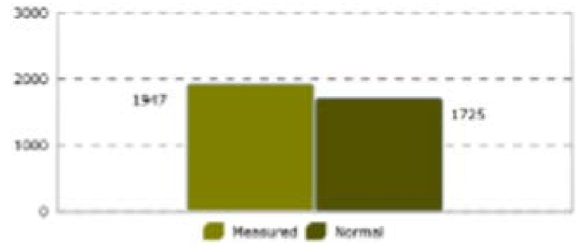


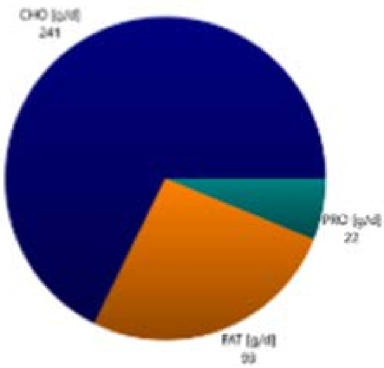
Figure 2B. Athlete 2 post-meal plan data

Athlete 3 (female) burned approximately 41 kcals per hour of carbohydrate and 36 kcals per hour of fat prior to the study. The athlete burned more carbohydrate than fat at rest. Post-study, the athlete utilized 34 kcals per hour of carbohydrate and 39 kcals per hour of fat. For this athlete, fat became the primary fuel source at rest over the course of the study. Athlete 3 also had a decrease in average amount of kcals burned per day, which also may indicate possible weight loss and lower energy intake throughout these days.

RMR	**1947 kcal/d**
Normal	1725 kcal/d
RMR/Weight	25.0 kcal/d/kg
RMR/BSA	1041 kcal/d/m2
Deviation Normal	+13 %

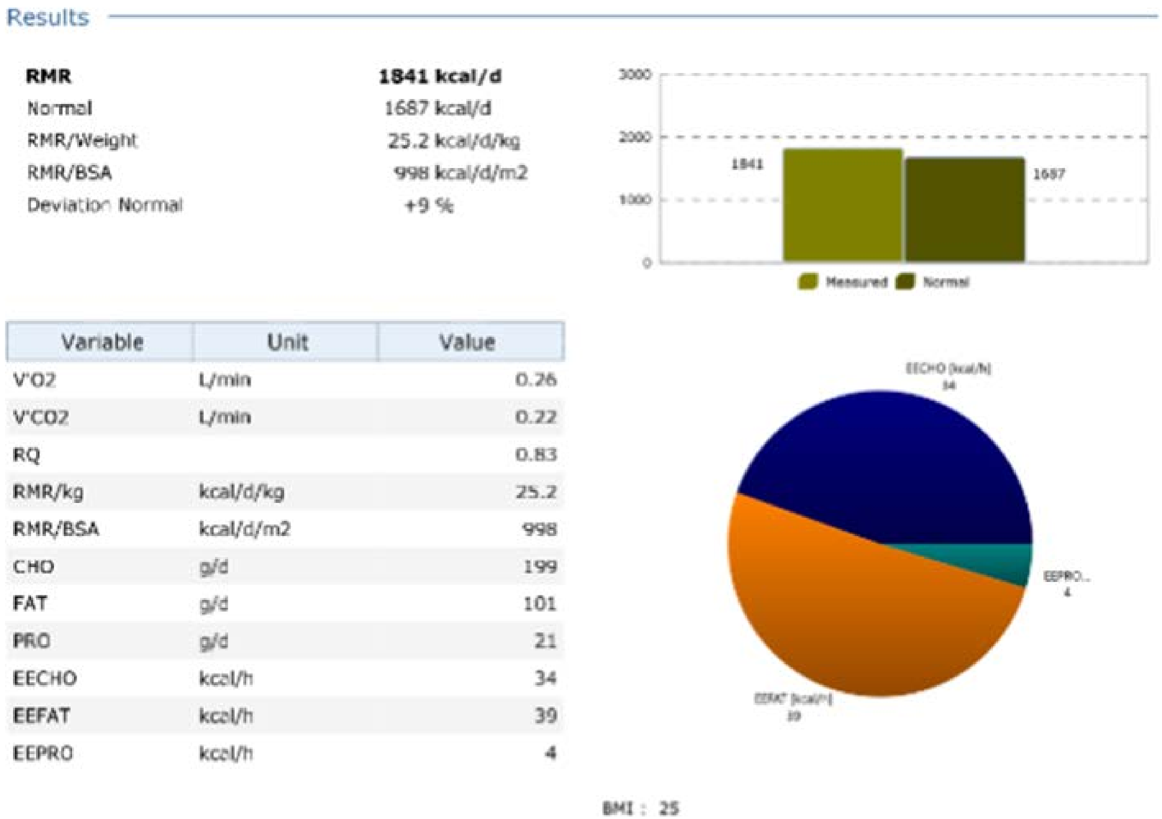


Variable	Unit	Value
V'O2	L/min	0.28
V'CO2	L/min	0.24
RQ		0.85
RMR/kg	kcal/d/kg	25.0
RMR/BSA	kcal/d/m2	1041
CHO	g/d	241
FAT	g/d	93
PRO	g/d	22
EECHO	kcal/h	41
EEFAT	kcal/h	36
EEPRO	kcal/h	4



BMI : 28

Figure 3A. Athlete 3 pre-meal plan data


Results

RMR	**1841 kcal/d**
Normal	1687 kcal/d
RMR/Weight	25.2 kcal/d/kg
RMR/BSA	998 kcal/d/m2
Deviation Normal	+9 %

Variable	Unit	Value
V'O2	L/min	0.26
V'CO2	L/min	0.22
RQ		0.83
RMR/kg	kcal/d/kg	25.2
RMR/BSA	kcal/d/m2	998
CHO	g/d	199
FAT	g/d	101
PRO	g/d	21
EECHO	kcal/h	34
EEFAT	kcal/h	39
EEPRO	kcal/h	4

Figure 3B. Athlete 3 post-meal plan data

The meal plans the athletes were provided with were based on training schedules, current dietary habits, body composition, and RMR results. However, each meal plan demonstrated metabolic efficiency concepts; providing carbohydrate sources prior to high-intensity exercise and higher fat sources during low-intensity exercise or rest. Figure 4A-4C is a sample meal plan the athletes were provided with. High-high intensity days indicate the athlete had two high-intensity training sessions; typically, one in the morning and one in the afternoon. High-low intensity days consisted of a high-intensity training session in the morning and a low-intensity training session in the afternoon. A low/rest day depicted a day where the athlete was not training or was engaging in low, steady-state exercise such as hiking or walking/running. The majority of two of the three athletes' meals and snacks were provided at the UFC Performance Institute with the dietitian/intern guidance. The male athlete did not live in state, therefore was given the meal plan but meals were not provided for him. All athletes confirmed they understood the meal plan and the type of macronutrients and portions they should be consuming in any given training schedule or situation. Nutrition staff was available to answer questions or concerns, both in person and remotely if need be.

	Athlete 1	**Athlete 2**	**Athlete 3**
Pre-RQ	.82	.91	.85
Post-RQ	.78	.87	.83
Pre-weight (lbs)	121	201	132
Post-weight (lbs)	120	194	132

Table 1: Pre and post assessment: RQ and weight

All RQ's were lowered from the initial assessment to the final assessment (Table 1). Athlete 1 had an RQ lowered by .04, Athlete 2 by .04, and Athlete 3 by .02. As mentioned above, an RQ closer to 0.7 indicates fat utilization at rest, and an RQ closer to 1.00 indicates primarily carbohydrate burning at rest. Athlete 1 lost 1 pound over the course of the study, Athlete 2 lost 7 pounds, and Athlete 3 remained the same. Athlete 2 was on a 1-2 lb per week weight loss plan over the course of 4 weeks.

Chapter 5 Discussion

Overall, the results indicated an increase in fat utilization at rest over the course of several weeks after being provided with a meal plan geared toward metabolic efficiency and using caloric measures from RMR testing. An athlete’s ability to burn primarily fat as a fuel source at rest helps with carbohydrate sparing during high-intensity exercise in addition to improving body composition by reducing total body fat. Each of the three athletes increased their fat utilization at rest while decreasing their carbohydrate utilization at rest, following the dietary intervention.

Athlete 1 was metabolically efficient (as she was primarily utilizing fat at rest) prior to the study but was able to increase fat as a fuel source at rest over the course of the study. In other words, the athlete became more metabolically efficient at rest by burning 9 more calories per hour from fat. Overall, this athlete was very well fat-adapted prior to the study. This athlete was provided with meals at the UFC PI, therefore nutrition staff was able to witness what this athlete was eating over the course of the few weeks. The athlete’s average kcal expenditure increased throughout the course of the study which was opposite as expected due to possible lower caloric consumption and therefore a decrease in energy expenditure. This may have been due to the athlete possibly not being fasted for 12 hours prior to the study or frequency of meals and snacks provided in the meal plan causing the metabolic rate to increase.

Athlete 2 was primarily a carbohydrate-burner at rest prior to the study. This athlete had fought a few weeks prior and was not quite as conditioned as he once was. Toward the completion of the study, this athlete was able to burn 11 kcal per hour more of fat, while decreasing his carbohydrate consumption as well. Therefore, he was trending toward a shift in substrate utilization but remained primarily a carbohydrate burner at rest. This athlete was out of the country during the intervention and was not able to be observed as closely as far as eating patterns and dietary habits over the course of the study.

Lastly, athlete 3 was an interesting case as she shifted from being primarily a carbohydrate burner to primarily a fat burner at rest. Although this athlete only increased 3 kcal per hour of fat at rest, carbohydrate utilization at rest decreased. This athlete was also provided with meals at the UFC PI, and therefore was observed more closely than athlete 2.

If an athlete can burn primarily fat at rest, they are able to spare carbohydrate for high-intensity exercise. By fueling the body with primarily starchy carbohydrates prior to high intensity exercise, glycogen is readily available for this type of exercise. With weight-dependent athletes, burning fat at rest may help improve body composition as this is imperative for weight-cutting and staying lean. Importantly, sports dietitians want to ensure the athlete is not overly conditioned to burning fat at rest, as this may inhibit an athlete's ability to use carbohydrates at high-intensity exercise.

Limitations

There were several limitations to this study. Compliance among the athletes in relation to the meal plan was not able to be measured. Two of the three athletes were provided with meals and snacks at the UFC Performance Institute, but food consumption after-hours was unknown. However, the athletes reported compliance with the meal plan after-hours. In addition, the male athlete did not live in state, so food consumption during the course of the study was unknown and only based on his dietary recall, although he reported being compliant 90% of the time. This athlete had a weight loss of about 7 pounds, so it is uncertain as to whether his change in substrate utilization was due to a lower calorie intake or actually from metabolic efficiency methods.

In addition, human error and machine error could have been a factor during the test which may have altered results. The UFC PI nutrition staff attempted to avoid these errors by proper calibration of the machine, correct placement of the athletes' mask, and proper testing procedures during the test. Moreover, the athlete should be fasted for at least 12 hours with no food and limited water prior to the study. Nutrition staff used athletes' word for indication that they were indeed fasted.

Lastly, all three of these athletes descend from a variety of areas across the world. Genetics could play a role in substrate utilization at rest. Athletes could be predisposed to these measures and it is unknown how great of an effect a change in dietary habits could have on these individuals. Therefore, this could be an interesting and noteworthy study for the future. Other future studies could include a larger sample size regarding metabolic efficiency at rest, metabolic efficacy as exercise intensity increases and a closer examination of athlete education and consults around meal planning and timing of meals for weight-dependent athletes.

Similar studies regarding macronutrient periodization have been studied. For example, this study implemented the concept of "sleep low" patterns which was also studied by Kerksick et al. (2018). In addition, several concepts from Bob Seebohor's book *Metabolic Efficiency Training* have been used in this study. There is limited research in regard to diet alterations and testing on RQ, specifically in weight-dependent athletes.

Role of RDN

The RDN was thoroughly involved throughout the study and the athletes utilized her daily for questions or concerns they had regarding their meals or snacks. Throughout the study, the local athletes were perceived to be in the action stage of change. Due to these athletes exemplifying motivation and compliance toward the diet, the RDN was available for educational purposes and support when needed. For the remote athlete, the RDN felt this athlete was in the contemplation stage throughout the study. The RDN had a larger role in not only education but counseling skills such as motivational interviewing. The athlete expressed concern regarding a few days with lack of compliance to the diet. The RDN provided support, empathy, and encouragement. Overall, the role of the RDN was imperative to the athletes in this study from a educational and counseling standpoint. Other disciplines at the UFC PI such as Strength and Conditioning or Physical Therapy are not familiar with the concept of metabolic efficiency to an extent that the RDN is. In addition, providing nutritional advice is out of their scope of practice. Therefore, the RDN was vital in this aspect.

Application to practice

For application to practice, these results can be helpful in the sports dietetics field for a variety of reasons. Dietitians would be able to indicate the percentage of substrate the athlete is burning at rest. Therefore, this information may be useful for athletes involved in weight-class sports and athletes who are going to be engaging in low intensity activity, knowing that their fuel source at rest is primarily fat. RMR data is helpful for this population to assess calorie intake based on the number of measured calories the athlete is burning at rest. This provides a baseline for exercise implications and different levels of intensity the athlete will engage in.

Future research

This study could be used as a baseline and introductory information for future research. A larger sample size and other athlete populations could benefit from this. It would be beneficial to know the body composition of the athlete before and after the study. Bioelectrical impedance (BIA) is one way to test for these values. For future studies, it would be helpful to assess if indeed muscle mass was increased and fat mass was decreased. In addition, it would be important to look at exercise testing such as metabolic efficiency testing on the treadmill provided at the UFC PI. This test measures the type of fuel an athlete burns as exercise intensity increases. As mentioned throughout this paper, the crossover point is the point at which carbohydrate becomes the dominate fuel source as exercise intensity increases. It would be interesting to study the effects of metabolic efficiency meal plans and implications this has during exercise.

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