Journal of Human Kinetics volume 65/2018, 125-137 DOI: 10.2478/hukin-2018-0102
Section II - Exercise Physiology & Sports Medicine

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No Modification in Blood Lipoprotein Concentration but Changes in Body Composition After 4 Weeks of Low Carbohydrate Diet (LCD) Followed by 7 Days of Carbohydrate Loading in Basketball Players

by

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Recently, low carbohydrate diets have become very popular due to their numerous health benefits. Unfortunately, little is known about their chronic effects on the blood lipid profile and other cardiovascular disease risk factors in athletic populations. We compared the results of a four week, well-planned low carbohydrate diet (LCD) followed by seven days of carbohydrate loading (Carbo-L) on fasting lipids - triacylglycerol's (TAG), LDL-C, HDL-C, total cholesterol (TCh), glucose, insulin and HOMA-IR levels in 11 competitive basketball players. During the experiment, we also measured body mass (BM) and body composition changes: body fat (BF), % of body fat (PBF), and fat free mass (FFM). Both diet procedures significantly changed the fasting serum concentration of TAG ($p < 0.05$) and body fat content (kg and %) ($p < 0.05$), without negative changes in FFM. The Carbo-L procedure increased ($p < 0.05$) fasting glucose levels significantly. A LCD may be suggested for athletes who want to reduce body mass and fat content without compromising muscle mass. Several weeks on a LCD does not change the lipoprotein - LDL-C and HDL-C level significantly, while a seven-day Carb-L procedure may increase body fat content and fasting glucose concentration. Such dietary procedures are recommended for team sport athletes to reduce fat mass, lipid profile disorders and insulin resistance.

***Key words**: nutrition, competitive athletes, lipoprotein profile, body mass, fat content, carbo loading.*

Introduction

For years, athletes have been searching for a diet that would enhance performance while reducing body fat and the risk of other disorders (Creighton et al., 2018; Greene et al., 2018; Maciejewska et al., 2017; McSwiney et al., 2017; Zajac et al., 2014). Till now athletes most often experiment with the low fat diets (LFD), low carbohydrate diets (LCD), and high protein diets (HPD) (Creighton et al., 2018; Greene et al., 2018; McSwiney et al., 2018; Paoli et al., 2013; Zajac et al., 2014). However particular sport disciplines are characterized by different exercise metabolism, which requires specific nutrition (Michalczyk et al., 2016). For example cyclists during competition can cover more than 200 km in a single stage, elite soccer players cover up to 12500 m during a 90 min match, while basketball players cover only 4-5 km during a FIBA rules game (Michalczyk et al., 2008, 2015; Ostojic et al., 2006). High carbohydrate diets, especially carbo-loading procedures, are recommended for endurance athletes like road cyclists or distance

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Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 65/2018 in December 2018.

runners to improve the performance of prolonged, continuous exercise lasting from 2 to 5 h (Burke et al., 2011; Hawley and Leckey, 2015). However for team sport athletes like basketball players, excess carbohydrates may not be necessary in the daily diet, due to the smaller training and shorter competition time. For dynamic team sports such as basketball consumption of carbohydrates is recommended before, during and after competition or training (Bartlett et al., 2015). The objective of liquid carbohydrate intake during and after exercise is related to muscle glycogen replenishment (Hawley and Leckey, 2015). Excessive carbohydrate consumption in team sport athletes with a limited daily energy expenditure could have unfavorable consequences on body composition and the blood lipid profile (Sharman et al., 2004).

Many researchers have shown that LCD has a positive effect on weight loss and body composition changes (Dashti et al., 2006; McSwiney et al., 2017; Paoli et al., 2013; Rhyu and Cho, 2014). A LCD increases postprandial energy expenditure (Brehm et al., 2003) by transforming dietary protein into carbohydrates. Secondly, consuming a LCD suppresses appetite by inhibiting gastric emptying, what spells into a long-lasting satiety following a meal (Erlanson-Albertsson and Mei, 2005). Modifications in appetite following a LCD may also be caused by changes in hormones such as leptin, PYY, insulin, cholecystokinin and ghrelin (Paoli et al., 2015).

The LCD lasting 1 to 12 months may decrease glucose and insulin concentration (Paoli et al., 2011), blood lipid serum, total cholesterol and LDL cholesterol levels (Creighton et al., 2018; Dashti et al., 2006), which are well recognized risk factors for diabetes and cardiovascular diseases in untrained males and females (Brinkworth et al., 2009; Westmann et al., 2003). Although some studies show variable responses in tCh and LDL-C after the LCD, there is a more consistent increase in HDL-C and a decrease in TAG, although the magnitude of change is variable across studies (Volek and Feinman, 2005). More significant reductions in TAG occurred when LCD was combined with fish-oil supplementation (Volek et al., 2000).

However, the impact of LCD on human health depends to a large degree on the type of fatty acids (FA) consumed in such a diet (Lovejoy et al., 2002). It is recommended that during a LCD, the majority of consumed fats includes monounsaturated (MUFAs) and polyunsaturated (PUFAs) acids, while saturated fats should be limited. Most studies confirm that a higher consumption of MUFAs and PUFAs improves insulin sensitivity, decreases systolic blood pressure, increases HDL-cholesterol and decreases serum triacylglycerol concentrations, in contrast to SFA (Escrich et al., 2007; Joris and Mensink, 2016; Simopoulos, 2008). MUFAs are significant sources of energy, they induce thermogenesis and fat oxidation, stimulate the immune system by suppression of lymphocyte proliferation, while reducing myocardial infarction, stroke, and death from CVD causes (Lovejoy et al., 2002; Simopoulos, 2008). The most important PUFAs, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which reduce the concentration of triglycerol in the blood, normalize blood pressure by increasing the level of prostacyclin, and they have an anticlotting effect (Joris and Mensink, 2016). EPA and DHA acids have anti-inflammatory, anti-carcinogenic, and anti-sclerotic properties (Simopoulos, 2008). Additionally, they reduce the concentration of LDL-cholesterol.

The current study evaluated the effects of a well-controlled 4-week low carbohydrate diet (LCD) followed by a 7-day carbohydrate loading protocol (Carbo-L) on the blood concentration of lipoproteins, glucose, insulin and the HOMA-IR index in competitive basketball players. Changes in body mass and body composition were also assessed.

Methods

Eleven male basketball players (age 24.27 ± 2.6 y; body mass (BM) 91.41 ± 5.17 kg; body height 192.8 ± 3.6 cm; fat free mass (FFM) 48.62 ± 6.62 kg; body fat content (%BF) 12.25 ± 2.38%) agreed to participate in this study. All study participants had at least five years of training experience and competed at the division I level of the Polish Basketball League. The mean volume of weekly training was 10.5 hours. During the five weeks of the experiment the athletes were fed a Low Carbohydrate Diet (LCD) for 4 weeks, followed by 7 days of carbohydrate loading (Carbo-L). There was no washout period between

the two feeding procedures. One month before the experiment began all participants consumed a standard Conventional Diet (CD) (Table 2). In the 5 weeks of the nutritional intervention the players maintained their normal training procedures, which included technical and tactical drills as well as intensive conditioning exercises. During the study the basketball players were in the precompetitive period, performing 5 training units per week with a scrimmage game played on Saturday. Each training session lasted from 90 to 120 min and included specific technical and tactical drills as well as conditioning exercises. The training intensity varied significantly from low (stretching, free throws – HR ≤ 120 bts/min) to submaximal during transition or full court press drills (HR ≥ 170 bts/min). All participants were non-smokers, healthy with a normal lipid profile. None of them had any previous experience with low carbohydrate or ketogenic diet before this study. None of the basketball players used the carbohydrate loading procedure before competition or fitness testing. Before the experiment began, all participants were informed about the study objectives and the accompanying risks and benefits. They were also informed about the possibility to withdraw from the experiment at any time. All basketball players read and signed an informed consent form to participate in the study. The testing procedures were approved by the Ethics Committee of the Academy of Physical Education in Katowice, Poland.

Dietary procedures

The dietary intervention lasted 5 weeks. Before constructing the individual isocaloric LCD, and Carbo-L, the resting metabolic rate (RMR) and the total daily energy expenditure (TDEE) associated with training were estimated. The TDEE was calculated according to the commonly accepted model (TDEE = AF × RMR) (Jarosz et al., 2012). The RMR was measured at the beginning of the experiment, before the 4-week LCD, as well as before the 7-day Carb-L, by means of an ergo spirometer MetaLyzer 3B (Cortex, Leipzig, Germany). AF was determined based on available indicators for athletes 2.0 (high activity) (Jarosz et al., 2012). Also, before the experiment, the subjects were asked to take home and complete the 72-h food diary (two weekdays and one weekend day). The dietary records were estimated by a nutritionist to assess previous feeding habits and daily caloric consumption.

The composition of diets is shown in Table 2. Before the experiment all participants consumed an isocaloric standard Conventional Diet (CD) (Table 2). The CD was composed of ~55% carbohydrates, ~15% protein and ~30% fat. The meals during the CD contained mainly whole grain products (wheat bread, bagel, pasta and rice), potatoes, beef, pork, sausages, poultry, cheese, fried eggs, vegetables, fruits, margarine, sunflower oil, whole milk as well as coffee with milk and sugar, tea, fruit juices, carbonated drinks like cola, and water. They had never experimented with low carbohydrate or carbo loading diet before. The LCD was composed in such a way that from all consumed fat, unsaturated fatty acids (mono and polyunsaturated) constituted 80% of daily calorie intake. The LCD was composed of 10% carbohydrates, 31% proteins and 59% fat. The LCD consisted of poultry, fish, beef, veal and lamb, dried beef, chopped meet tartare, carpaccio and cured ham, olive oil, butter, green vegetables without restriction (raw and cooked), boiled eggs and seasoned cheese (e.g. mozzarella, halloumi). Warm drinks were restricted to tea and coffee without sugar and herbal extracts. The foods and drinks that athletes avoided included alcohol and any sweets like sugar or honey. They also did not consume white bread, pasta, white rice, sweet milk, fruit yogurt, sweets, soluble tea and barley coffee. The Carbo-L diet contained carbohydrates, mainly with a low glycaemic index like whole grain bread and pasta, graham rolls, whole grain rice, legumes, raw vegetables, poultry, beef, pork and fish. Only after training, the athletes consumed medium or high glycaemic index snacks like bananas, honey, figs, dactyls or meals with white rice, potatoes, boiled carrots and beetroots. The meals were prepared in the form of 24 h menus for seven days of the week. They also consisted of instructions for five meals per day. The particular diet composition was analyzed using DIETETYK 6.0 software (Jumar, Poland).

Our study was unique in the sense that both the LCD and the Carbo-L diets were composed of high quality food products. In the LCD, the subjects consumed healthy fats, mainly monounsaturated fatty acids from olive oil, dairy products and nuts which accounted for more than 50% of all fatty acids consumed. The LCD also

contained polyunsaturated fatty acids n-6 and n-3, in a ratio not exceeding 4-5 : 1. The diet included the consumption of fish, like mackerel and sardines which are rich in n-3 fatty acids. Additionally, the LCD included high-quality protein products such as fish, meat, eggs and dairy products. On the other hand, in the Carbo-L diet, the subjects did not eat processed carbohydrates - fast foods, sweets and carbonated drinks. In the Carbo-L protocol, the participants ate healthy carbohydrates such as cereals, rice, buckwheat, millet, and fruits. They also consumed high-quality protein and fat products, similar to the LCD.

Diet control

During the 5 weeks of the experiment the study participants lived in the dormitory and were fed at the Academy's cafeteria. All meals were planed and supervised by a nutritionist. The quality and quantity of the food products were strictly controlled, maintaining proper proportions between the major macronutrients. During the 4 weeks of the LCD the athletes consumed 4 main meals and 1 snack, while on the Carbo-L diet they consumed 4 main meals and 2 snacks. The main meals were prepared and consumed at the cafeteria, whereas the snacks were packed and eaten after the training sessions.

Experimental design

Before (after CD diet), and after four weeks of the LCD, as well as after the 7 day Carbo-L, fasting blood evaluations and somatic measures were carried out to determine several anthropometric and biochemical variables. The analysis of body mass and body composition was made using the bioelectrical impedance method with an eight-electrode system (InBody 720, Biospace Co., Tokyo, Japan). The anthropometric data of athletes before the intervention, after the LCD and after Carbo-L are presented in Table 2. Before each measurement, the following testing procedures were maintained: the last meal preceding the body composition evaluations was consumed at 20:00, and then the subjects ingested 1 L of still medium-mineralised water. The subjects did not drink alcohol 48 hours before the test and immediately before the measurement they emptied their bladders.

Biochemical analysis

Before and after the LCD and after Carbo-L the following biochemical variables were evaluated in all study participants: triglycerides (TAG, mg/dl), total cholesterol (tCh, ng/dl), high density cholesterol (HDL-C,mg/dl), low density cholesterol (LDL-C, ng/dl) and glucose (GL, mg/dl) using Randox UK diagnostic kits (TRIGS-210, CHOL-201, LDL-2656, HDL-2652, Ranbut, Gluc-PAP). The level of insulin (I, IU/ml) in blood serum by radioimmunoassay (RIA) was also determined, using diagnostic sets, DSL 1600 DA RIA, Diagnostic System Laboratories, Webster, TX USA. HOMA-IR was calculated from the formula fasting insulin level x fasting glucose divided by 22.5.

Statistical analysis

Age, body mass and body composition, as well as biochemical variables were expressed as mean ± SD. Before using the parametric test, the assumption of normality was verified using the Kolmogorov-Smirnov test. A one way ANOVA was used with significance set at $p < 0.05$. When appropriate a Bonferroni post hoc test was used to compare selected data, the effect size (eta-squared; η2) of each test was calculated for all analyses. The effect size was classified according to Hopkins: 0.20, 0.60, 1.2, 2.0 and 4.0 for small, moderate, large, very large and huge, respectively (Hopkins, 2010; Maszczyk, et al., 2014, 2016, 2018). The remaining analyses were performed using STATISTICA (Stat Soft, Inc. (2018) version 12).

Results

Table 2, Figures 1 and 2 present the results of body mass and body composition after the CD, the LCD and the Carbo-L. In Table 3 the lipoprotein profile, glucose and insulin concentration, as well as the HOMA-IR values are presented after the CD, LCD and Carbo-L intervention.

Significant differences in TAG and glucose concentrations were observed after the LCD and the Carbo-L interventions (Table 3). The Bonferroni post hoc test revealed a significantly lower concentration of TAG ($F = 39.89$; $\eta 2 = 0.721$; $p = 0.002$) after the LCD. At the same time, the test revealed a significantly higher concentration of TAG ($F = 40.29$; $\eta 2 = 0.831$; $p = 0.002$) and glucose concentration ($F = 18.23$; $\eta 2 = 0.496$; $p = 0.004$) after the Carbo-L compared to CD. In turn, as can be seen in Table 3, there were no statistically significant differences in tCh, LDL-C HDL-C

concentrations after the LCD and the Carbo-L compared to the CD. No statistically significant differences were observed in I concentration and HOMA-IR value after the LCD and the Carbo-L compared to the CD.

The one way repeated measures ANOVA revealed a statistically significant effect of the dietary interventions on BF and PBF (Figures 1 and 2). The Bonferroni post hoc test revealed a statistically significant decrease in BF ($F = 31.12$; $\eta 2 = 0.626$; $p = 0.003$) and PBF ($F = 29.13$; $\eta 2 = 0.567$; $p = 0.003$) after the LCD. Significantly lower BF ($F = 28.12$; $\eta 2 = 0.495$; $p = 0.004$) and PBF ($F = 27.88$; $\eta 2 = 0.4867$; $p = 0.004$) was observed after the Carbo-L compared to the CD and higher compared to the LCD, yet statistically not significant.

Table 1

Average macronutrients and total energy intake during CD, LCD and Carbo–L.

Contents	CD Mean ± SD	LCD Mean ± SD	Carbo-L Mean ± SD
CHO, %	54 ± 6.1	10 ± 0.5	75 ± 3
Pro, %	15 ± 6.3	31 ± 2.3	16 ± 3
Fat, %	31 ± 4.3	59 ± 3.6	9 ± 1.6
SFA, g	48 ± 6.1	30 ± 4.2	11 ± 2.4
MUFAs, g	61 ± 5.2	128 ± 12.3	13 ± 1.6
PUFAs, g	20 ± 2	68 ± 4.5	10 ± 1.7
n-3, g	3.2 ± 0.2	24.4 ± 0.6	1.8 ± 0.3
n-6, g	16.1 ± 6	47.7 ± 2.7	7.5 ±
n-6 /n- 3, g	~5 ± 1	~2 ± 1	~4 ± 1
TEI, kcal	3740 ± 53	3758 ± 42	3752 ± 15
TEI, kJ	15 658.63 ± 221	15 733.99 ± 175	15 708.87 ± 62

CHO - Carbohydrate, PRO - Proteins, SFA - Saturated Fatty Acids, MUFAs - Monounsaturated Fatty Acids, PUFAs - Polyunsaturated Fatty Acids, n-3 - omega 3, n-6 - omega 6, TEI - Total Energy Intake

Table 2

Body composition results after CD, LCD and Carbo-L.

Variables	After CD Mean ± SD	After LCD Mean ± SD	After Carbo-L Mean ± SD
BM (kg)	93.61 ± 5.17	90.38 ± 3.12	91.82 ± 4.32
FFM (kg)	50.62 ± 4.88	48.20 ± 3.65	49.92 ± 3.84

**- $p < 0.05$ significant difference to the After CD ($p < 0.05$)*

Table 3

Biochemical variable changes after CD, LCD and Carbo-L.

Variables	After CD Mean ± SD	After LCD Mean ± SD	After Carbo-L Mean ± SD
tCh (mg/dl)	176.55 ± 18.57	222.64 ± 15.20	194.64 ± 13.75
HDL-C (mg/dl)	47.51 ± 8.44	62.42 ± 14.15	57,.80 ± 5.56
LDL-C (mg/dl)	108.08 ± 5.72	91.50 ± 6.59	96.11 ± 11.51
TAG (mg/dl)	93.38 ± 13.64	78.75** ± 10.60	119.84* ± 15.15
Glucose (mg/dl)	94.91 ± 6.23	87.32 ± 5.73	95.88* ± 6.71
I (IU/ml)	5.89 ± 3,25	4.12 ± 2,61	6.67 ± 3,65
HOMA-IR	1.26 ± 0.77	1.03 ± 0.56	1.6 ± 0.93

**- significant differences compared to the After CD (p < 0.05)*

***- significant differences compared to the After CD (p < 0.01)*

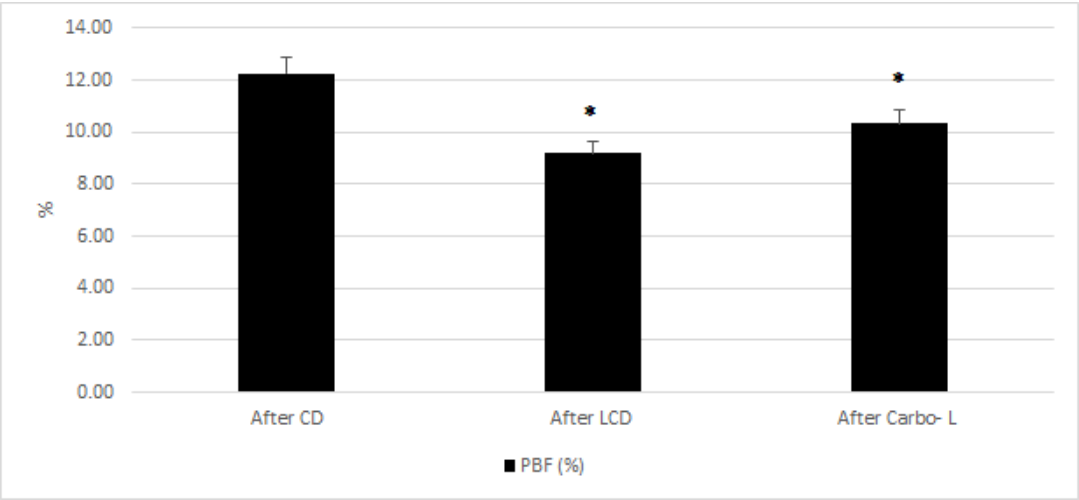

Figure 1.

Differences in fat content (PBF) after CD, LCD and Carbo-L;

**- significant differences compared to the CD (p < 0.05)*

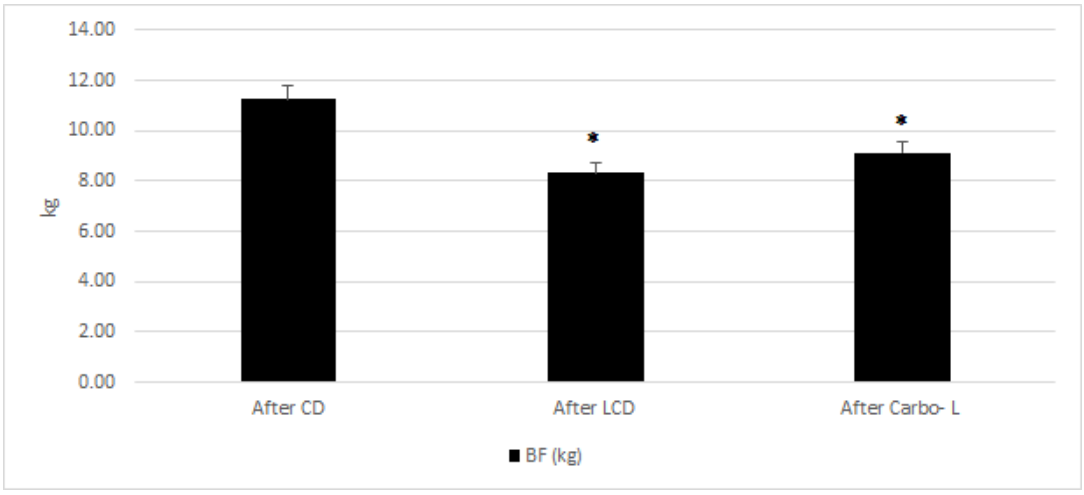

Figure 2.

Differences in fat mass (BF) after CD, LCD and Carbo-L;
**- significant differences compared to the CD ($p < 0.05$)*

Discussion

In the past decade or two, numerous studies have been carried out on the impact of low carbohydrate diets to enhance exercise performance in athletes, reduce fat content and decrease the risk of dyslipidaemia or insulin resistance in overweight and obese people (Burke et al., 2017; Cassady et al., 2007; McSwiney et al., 2017; Sharman et al., 2004; Zając et al., 2014). The results of these studies allow researchers to propose this diet as a solution to the rapidly progressing problems of overweight and obesity, as well as lipoprotein diseases in trained and untrained subjects (Maciejewska et al., 2017; Nordmann et al., 2006; Sharman et al., 2004). Many researchers have shown that low carbohydrate diets have a positive effect on triglyceride levels (Creighton et al., 2018; Nordmann et al., 2006; Sharman et al., 2004), adipose tissue (Brehm et al., 2003; Dashti et al., 2006), blood glucose concentration, HOMA - IR and CRP (Nordman et al., 2006). Recently even the World Health Organization (WHO) and other international authorities have made new dietary recommendations urging a limitation of daily carbohydrate consumption, especially for overweight and obese people, as well as those with diabetes (DeSalvo et al., 2016; WHO, 2015). The new concepts of WHO show that there are definite changes in the perception of diets for adults, with a significant reduction in carbohydrate consumption.

In recent years, researchers throughout the world have evaluated the effect of a low carbohydrate diet on the lipid profile (Creighton et al., 2017; Dashti et al., 2006; Paoli et al., 2011). Lipoprotein disorders are a substantial factor in the development of atherosclerosis and other cardiovascular diseases. Particularly the elevated level of LDL-C in athletes, due to the higher oxygen uptake during exercise, will promote their oxidation, and this may increase muscle cell membrane damage as well as atherosclerotic

changes in blood vessels (Volek et al., 2000). Although our subjects were young, healthy men, such disorders are often observed in athletic populations. In our experiment, we evaluated the effects of a LCD, and a Carbo-L diet on the lipid profile of competitive basketball players. The results indicate that after 4 weeks of the LCD no significant decrease in LDL-C, as well as no significant increase in HDL-C and tCh were observed, but only a significant decrease in TAG. Opposite changes were recorded after the 7-day carbohydrate loading phase, although statistically significant only in case of the TAG. These results have confirmed that the low carbohydrate diet does not adversely affect the lipid profile (Dashti et al., 2006; Paoli et al., 2011; Volek and Feinman, 2005). These effects may be linked to the high quality of products used in the LCD (Volek and Feinman, 2005). In our study, the athletes consumed mainly MUFAs from olive oil, dairy products and nuts, as well as PUFAs - n-3 from fish. It is known that both n-3 and MUFAs have a positive effect on the blood lipid profile (Cassady et al., 2007). The lack of adverse consequences in lipid metabolism observed in our study may be attributed to well documented reduction of blood lipid (TAG, tCh) and lipoprotein (HDL-C, LDL-C) levels caused by both the low carbohydrate diet (Brinkworth et al., 2009) and/or regular exercise (Philippe et al., 2017). There are many studies in which the positive effect of low-carb diet on the lipid profile was observed (Paoli et al., 2011; Tay et al., 2015; Volek and Feinman, 2005). Volek compared a low carbohydrate diet with a low-fat diet and found that after 12 weeks, SFA in TG and cholesterol ester were lower in the LCD group than the LFD group even though the low carbohydrate group had a 3-fold higher intake of dietary SFA (Volek and Feinman, 2005). In the subjects examined after four weeks of LCD, there was a downward trend in LDL-C, which is classified as a strongly prominent pro arteriosclerosis factor. This can be considered a positive effect of the applied low carbohydrate diet. Similarly, Tay et al. (2015), after a low carbohydrate diet which was high in unsaturated fat and low in saturated fat, achieved greater improvements in the lipid profile, exemplified by higher HDL and lower LDL and TG. Also, Brinkworth et al. (2009), after a few weeks of using a low carbohydrate diet in obese people observed a significant decrease in TAG, LDL and an increase in HDL compared with a low fat diet. On the other hand, Dashti et al. (2006) experimented with a VLCKD, the most restricted form of all low carbohydrate diets, and showed that people with a high baseline LDL-C responded much stronger to this intervention. These results are supported by research of Paoli et al. (2011), who used a low carbohydrate/high protein diet with a high content of monounsaturated fatty acids, and also observed decreases in unfavorable LDL lipoprotein fractions. Paoli et al. (2011) explain this phenomenon by the high content of unsaturated fats and low amount of saturated fats. This confirms that both the MUFAs and PUFAs have a positive effect on the lipid profile (Simopoulos, 2008). Some researchers show unfavorable responses to the low-carb diet with a predominance of saturated fats, which cause an increase in tCh, LDL and TAG (Nordmann et al., 2006).

Compared to other team sports, basketball players have a relatively high body mass, which varies at the elite level from 80 to 120 kg, depending on the position on the court (Abdelkrim et al., 2010; Ostojic et al., 2006). Point guards and shooting guards are rather lean (8.9 ± 3.1% BF), small forwards are usually much taller, but also lean (10.1 ± 3.2% BF), while power forwards and centers are tall, muscular and have more body fat (14.4 ± 5.6% PBF) (Ostojic et al., 2006). It has been well documented that decreased fat content in athletes allows for increased speed and power (Havemann et al., 2006). There is a significant amount of evidence indicating that low carbohydrate diets reduce body fat (Brinkworth et al., 2009; Paoli et al., 2011). In our experiment, the LCD significantly affected body fat in the studied basketball players. The benefits of the LCD were revealed in absolute (kg) as well as relative (%) reduction of body fat. Also, after the Carbo-L, we observed lower body fat content in comparison to the CD and before LCD, yet higher than after the LCD. Similar results were presented by Paoli et al. (2011) and Zajac et al. (2014). Our results confirm the concept that the level of body fat does not depend on the amount of fat consumed in the diet, but on the amount and quality of carbohydrate consumption. This thesis explains the paradox of today's diet of modern adults

living in highly developed countries. For several years they have been encouraged to consume rather low-fat diets, with light products, i.e. in which fats have been replaced with starch and other sugars, which has caused an epidemic of overweight and obesity. The increase in BF following the Carbo-L procedure may be related to the increased blood concentration of insulin and glucose. Insulin is a hormone that regulates blood concentration of glucose. When the level of glucose rises, as in the carbohydrate loading procedure, an abrupt insulin secretion occurs, which subsequently binds to its receptors located in different tissues, including adipose tissue. This complex translocates GLUT4 into cellular membranes causing intracellular efflux of glucose and thereby stimulating lipogenesis. The increased consumption of carbohydrates during the Carbo-L procedure increased the rate of lipogenesis, what was evidenced in the increases of body mass and body fat content.

In our experiment, besides body fat changes, we also evaluated body mass and FFM changes (Rhyu and Cho, 2014). In the studied group of basketball players, a non-significant tendency to reduce body mass and fat free mass after the LCD was observed, while an increase of these variables after the Carbo-L period. This phenomenon can be explained by the fact that both diets were isocaloric, and this guaranteed the supply of adequate energy, especially protein, and did not lead to catabolism of muscle tissue (Paoli et al., 2011). It was extremely important not to reduce FFM during the experiment carried out during the pre-competitive season since significant fluctuations in muscle mass during this period could have a negative impact on players' strength and power and consequently on basketball performance. The FFM is defined as the total content of muscle proteins, water and bone tissue (Lukaski, 2009). It should be remembered that muscle mass is directly influenced by the level of muscle glycogen, which is almost twice as high in competitive athletes in comparison to untrained subjects (Hearris et al., 2018). The main substrate for muscle glycogen resynthesis includes carbohydrates derived from the diet. The low intake of carbohydrates during the LCD may explain the non-significant decrease in FFM after the 4-week intervention (Brehm et al., 2003). In turn, the increase of FFM after the seven-day Carbo-L procedure was most likely due to the increased carbohydrate intake and greater synthesis and storage of muscle glycogen (Hearris et al., 2018). Thus, the fluctuations in FFM during the 5 week intervention may have resulted from the depletion of glycogen during the LCD and subsequent significant replenishment of this substrate after the Carbo-L procedure. Another critical factor supporting minor changes in FFM during the LCD is the high protein consumption, which accounted for over 30% of the total daily calorie intake (Havemann et al., 2006). The significant intake of high quality protein during this intervention most likely inhibited muscle catabolism (Wilk et al., 2018). Similar results were presented by Paoli et al. (2011) and Rhyu and Cho (2014).

In the majority, but not in all studies in which the effect of low carbohydrate diets on body composition was examined, positive effects of reducing body fat were obtained (Brehm et al., 2003; Sharman et al., 2004). The factor which probably had a significant impact on the divergent results was the inconsistent methodology of research used in particular experiments. The lack of control over the type and quality of products, which was revealed in available research (Brinkworth et al., 2009; Nordmann et al., 2006), may have influenced the results. In our experiment, the subjects consumed high-quality products, both in the 4-week LCD and during the seven days of carbohydrate loading, which is an innovative solution in this type of research. The meals in the LCD and Carbo-L procedures were composed of high quality protein with a full amino-acid profile. The athletes consumed beef, poultry, eggs and fish. Additionally, they ate soy protein and other vegetable proteins. The MUFAs and PUFAs were derived from avocado, nuts, olive oil and several types of seeds. During the experiment the athletes avoided saturated fats, thus they limited the consumption of pork, bacon, ham and sausages, liver, yellow cheese and other deep fried products. We have observed that many obese people choosing the LCD or the more restrictive LCKD for health reasons or to reduce fat, consume excess amounts of saturated fats due to the low cost and great access to such food products.

It seems logical that limiting the intake of

carbohydrates will lead to a decrease in glucose, insulin and the insulin resistance index - HOMA-IR (Krebs et al., 2013; Maciejewska et al., 2017). On the other hand, the increase in carbohydrate intake will show an inverse reaction. Therefore, in our experiment we measured changes in the level of these variables. However, our hypothesis that the LCD would significantly reduce the level of these variables and the carbohydrate loading procedure would increase them was not confirmed (Sharman et al., 2004). After the LCD, we recorded a decrease in all three variables, although these changes were not statistically significant (Krebs et al., 2013). Despite the high intake of MUFAs in our dietary protocol, which penetrate the cell membrane while increasing the receptors affinity to insulin (Paniagua et al., 2007), the lack of significant changes in insulin and HOMA-IR resulted most likely from a relatively high consumption of carbohydrates which amounted to 96g/d (Sharman et al., 2004). An alternative source of glucose for athletes on our LCD included amino acids derived from protein and glycerol coming from triglycerides. Both of these substrates may be used for glucose resynthesis in the liver through gluconeogenesis. Additionally, the high consumption of BCAA could have influenced the non-significant changes in HOMA-IR, since these amino acids may increase insulin resistance through the activation of mammalian target of rapamycin complex 1 (mTORC1) (Yoon, 2016). However, after the carbohydrate loading, we recorded an increase in all three, yet only the increase in glucose concentration was statistically significant (Sharman et al., 2004). The lack of statistically significant changes in most measured variables at both stages of the dietary intervention could be explained by the same mechanisms as the changes in LDL-C or HDL-C levels. At the beginning of the experiment, all biochemical variables studied were within the reference values for young healthy adults. We only observed a significant increase in the blood concentration of glucose after the weekly loading procedure, what shows how quickly the body responds to the high supply of carbohydrates in the diet. The obtained results, especially after the LCD, support another conclusion that a diet with a limited amount of carbohydrates has an positive effect on glucose metabolism and can be recommended to people with elevated levels of glucose, insulin and HOMA-IR (Krebs et al., 2013; Maciejewska et al., 2017).

Conclusions

There were several limitations to the study of which the most prominent include a small number of subjects and the lack of a control group. This can be explained by the common problem of recruiting professional athletes for scientific experiments during the competitive or precompetitive season. Considering these limitations and taking into account that we evaluated well trained semi-professional basketball players, we can conclude that a 4-week LCD allows for a reduction of body fat with a concomitant preservation of fat free mass. The low carbohydrate diet also shows positive changes in fasting blood triacylglycerol's, glucose, insulin, HOMA-IR and LDL-C, yet they are not significant. Short term carbohydrate loading procedures increase body muscle and fat mass, as well as fasting glucose levels within several days. The gains in body mass are most likely due to greater glycogen synthesis and storage in the muscle. The LCD may be used by team sport athletes to improve body composition.

Acknowledgements

This work was supported by the Ministry of Science and Higher Education of Poland under Grant NRSA4 040 54.

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