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Keto-adaptation enhances exercise performance and body composition responses to training in endurance athletes

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ABSTRACT

Background. Low-carbohydrate diets have recently grown in popularity among endurance athletes, yet little is known about the long-term (>4 wk) performance implications of consuming a low-carbohydrate high fat ketogenic diet (LCKD) in well-trained athletes.

Methods. Twenty male endurance-trained athletes (age 33 ± 11 y, body mass 80 ± 11 kg; BMI 24.7 ± 3.1 kg/m^2) who habitually consumed a carbohydrate-based diet, self-selected into a high-carbohydrate (HC) group (n = 11, %carbohydrate:protein:fat = 65:14:20), or a LCKD group (n = 9, 6:17:77). Both groups performed the same training intervention (endurance, strength and high intensity interval training (HIIT)). Prior to and following successful completion of 12-weeks of diet and training, participants had their body composition assessed, and completed a 100 km time trial (TT), six second (SS) sprint, and a critical power test (CPT). During post-intervention testing the HC group consumed 30–60 g/h carbohydrate, whereas the LCKD group consumed water, and electrolytes.

Results. The LCKD group experienced a significantly greater decrease in body mass (HC −0.8 kg, LCKD −5.9 kg; P = 0.006, effect size (ES): 0.338) and percentage body fat percentage (HC −0.7%, LCKD −5.2%; P = 0.008, ES: 0.346). Fasting serum beta-hydroxybutyrate (βHB) significantly increased from 0.1 at baseline to 0.5 mmol/L in the LCKD group (P = 0.011, ES: 0.403) in week 12. There was no significant change in performance of the 100 km TT between groups (HC −1.13 min·s, LCKD −4.07 min·s, P = 0.057, ES: 0.196). SS sprint peak power increased by 0.8 watts per kilogram bodyweight (w/kg) in the LCKD group, versus a −0.1 w/kg reduction in the HC group (P = 0.025, ES: 0.263). CPT peak power decreased by −0.7 w/kg in the HC group, and increased by 1.4 w/kg in the LCKD group (P = 0.047, ES: 0.212). Fat oxidation in the LCKD group was significantly greater throughout the 100 km TT.

Conclusions. Compared to a HC comparison group, a 12-week period of keto-adaptation and exercise training, enhanced body composition, fat oxidation during exercise, and specific measures of performance relevant to competitive endurance athletes.

1. Introduction

Traditional sports nutrition guidelines recommend consumption of high-carbohydrate diets for endurance performance [1,2], yet a growing number of athletes have adopted a LCKD

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approach [3,4]. Endurance performance is limited when endogenous carbohydrates are the dominant fuel [5,6], necessitating provision of exogenous carbohydrate during exercise [7]. A LCKD increases oxidation of endogenous fat stores [8] partially relieving an athlete's dependency on glucose [4]. There is no universally agreed definition for a LCKD. The level of carbohydrate and protein restriction required to induce nutritional ketosis varies, however, some guidelines recommend consuming >75% of energy from fat, moderate protein (1.76–2.2 g per kg lean mass), and <50 g/d carbohydrate [5].

There is a scarcity of investigations examining the effects of a LCKD on performance [9–12] with a greater number of investigations examining low-carbohydrate high fat (LCHF) diets and performance [13–17]. A recent review [3] defined a LCHF diet to contain >60% energy from fat, with moderate levels of carbohydrate restriction (<25% energy). This definition of a LCHF diet is similar to a LCKD diet, both are higher in dietary fat than a traditional diet, and restrict carbohydrates. However, a LCHF diet may not optimise metabolic adaptations associated with accelerated fat oxidation and ketone-related metabolic and signaling effects [4,8]. LCHF diet investigations have focused on short (7–14 days) [13–15], to medium term adaptation periods (14–35 days) [16–17] in athletes. These investigations have reported consistent alterations in fuel utilization, and exercise metabolism in fasted, and carbohydrate depleted states, but fail to test the hypothesis surrounding long-term keto-adaptation and exercise performance [8]. When well-formulated ketogenic diets are implemented for a minimum of four weeks, enhanced fat oxidation rates are observed, with no decrement in aerobic capacity [9]. What happens to exercise performance beyond 4 weeks of keto-adaptation remains unclear, but empirically several endurance athletes using this approach remain highly competitive [8].

Changes in performance due to consumption of LCHF diets are mixed [13–17]. A recent cross sectional study examined the metabolic characteristics of keto-adapted ultra-endurance athletes who consumed a LCKD for 9–36 months [8]. Peak and sub-maximal fat oxidation rates during exercise in keto-adapted participants were more than two-fold higher compared to HC counterparts, and 50% higher than peak rates previously reported [18]. Two of the most notable differences between the LCKD investigation [4], and the current body of LCHF research are the level of carbohydrate restriction, and the length of the adaptation period.

LCKD research on performance has focused on short to medium term adaptation periods (21–30 days) [9–12], possibly due to challenges of long term dietary interventions. Two of these investigations should not be categorised as "ketogenic", since protein [11], and carbohydrate [10], were not sufficiently restricted. Nonetheless, strength, and time to exhaustion were not negatively affected [9–12], however two trials reported a decreased ability to perform at higher intensities [11], and decreased exercise economy [12]. Despite a lack of experimental scientific literature advocating clear performance benefits of adapting to a LCKD diet, interest in this dietary paradigm has continued to gather traction [3,4,19]. Keto-adaptation is believed to unlock a much larger fuel tank versus a carbohydrate-based diet [4,5]; hence reducing an athlete's need for carbohydrate supplementation during exercise. Thus, unlike previous long term cross-sectional LCKD investigations where keto-adaptation had already taken place [8,20] we designed an experimental study to investigate the long-term (12-week) performance implications of consuming a LCKD diet on performance relevant to competitive endurance athletes, and tested the hypothesis that a keto-adapted athlete can maintain/improve performance on a LCKD. This research also involved incorporation of training programme to enhance mitochondrial biogenesis and hence fuel utilization, an aspect not incorporated within previous research.

2. Methods

2.1. *Experimental Approach*

This was a non-randomised control trial comparing long term performance implications of consuming a HC and LCKD, in male endurance trained athletes. A non-randomised approach was chosen due to the length of the adaptation period, and to promote dietary adherence. Participants were informed of the purpose, and any risks associated with taking part, prior to written consent being obtained. The investigation was approved by the research ethics committee at Waterford Institute of Technology, IE. At baseline participants completed a DXA scan, SS sprint, 100 km TT and CPT. Following baseline testing both groups began a 12-week dietary and training intervention (endurance, strength, and HIIT). Participants returned at the end of week 12 and repeated the testing protocol.

2.2. *Participants*

Forty-seven male endurance trained athletes (18–40 years) were enrolled. Twenty participants completed all requirements associated with the current study (Table 1). For this

Table 1 – Subject characteristics.

	HC diet (*n* = 11)		LCKD diet (*n* = 9)		*t*-Test
	Mean ± SD	Range	Mean ± SD	Range	P Value
Age, years	32.1 ± 6.4	20.0–38.0	33.8 ± 6.9	19.0–40.0	0.566
Height, cm	181.2 ± 4.9	177.0–192.1	183.1 ± 5.5	175.5–191.6	0.408
BMI, kg/m^2	23.9 ± 2.9	20.0–30.5	25.6 ± 3.0	22.2–31.2	0.090