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Ketogenic and High-Carbohydrate Diets in Cyclists and Triathletes: Performance Indicators and Methodological Considerations From a Pilot Study

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Endurance athletes frequently employ nutritional strategies to enhance performance. While professional organizations recommend high carbohydrate diets to maximize performance, many athletes, and researchers have recently shown renewed interest in the ketogenic diet in hopes to promote "fat adaptation", which would allow athletes to make use of the essentially unlimited energy resources from stored body fat. This would circumvent one fatigue mechanism, the depletion of muscle glycogen stores, that has been considered central to performance outcomes in endurance events. The present study investigated the effects of participants' habitual diet, high carbohydrate diet, and ketogenic diet on endurance performance in a 30-km simulated cycling time trial, physiological responses during the time trial, and muscle session fuel percentile before and after the time trial using ultrasonic imaging. Due to the COVID-19 pandemic, data collection ceased after only six recreational cyclists and triathletes (f = 4, m = 2; age: 37.2 [12.2]; VO2max: 46.8 [6.8] ml/kg/min; weekly cycling distance: 225.3 [64.2] km). Due to the small sample size, we do not report inferential statistics for our primary outcome measure, cycling performance. Participants produced the lowest mean power output during the time trial following the ketogenic diet (172 +/- 93 W) and the highest mean power output following the high carbohydrate diet (200 [92] W). Oxygen consumption, heart rate, and perceived exertion during the time trial were similar in all conditions. Fat oxidation rates were highest in the ketogenic diet condition (0.62 [0.11] g/min) and lowest in the high carbohydrate condition (0.14 [0.11] g/min). Session fuel percentile was lower following the ketogenic diet compared with the habitual diet (Mean Difference = -10.0 [12.7] %) and lower following the time trial compared with fasted resting values across all conditions. We discuss methodological considerations into the use of exercise equipment, nutritional interventions, and statistical analysis strategies for study designs like the present. Further research is needed to assess the impact of high carbohydrate and ketogenic diets on time trial performance in this population. ClinicalTrials.gov Identifier: NCT04097171; OSF preregistration: https://osf.io/ujx6e/

1. Introduction

Nutritional interventions remain at the forefront of strategies employed by athletes to enhance their performance (Thomas et al., 2016). Commonly employed approaches among endurance athletes include a high daily intake of dietary carbohydrate (6-10 g/kg/day) and carbohydrate loading (10-12 g/kg/day) before an event, since low muscle glycogen is a well-established cause of fatigue (Jeukendrup, 2004, 2011). Contrary to this traditionally favored strategy, endurance athletes and researchers have recently began expressing increased interest in a low carbohydrate, high fat ketogenic diet again (Burke, 2017). When following a ketogenic diet, athletes typically limit their carbohydrate intake to <50 g or 5-10% of their total daily energy intake (Feinman et al., 2015). The proposed benefit of this diet approach is "fat adaptation", enabling the oxidation of fat as the main energy substrate at exercise intensities (e.g. >70% of maximal oxygen consumption VO_2max) where the oxidation of carbohydrate would typically predominate (Carey et al., 1985; Lambert et al., 1994, 1997). This would essentially create unlimited energy resources, as the body can store more than 74,000 kcal in subcutaneous, visceral, and intramuscular fat (Kenney et al., 2020). Despite its recent resurgence in popularity, the ketogenic diet's restrictive nature counters the current dietary recommendations of several professional organizations, which state that low carbohydrate availability before exercise is a significant component of diminished exercise capacity and performance (Burke et al., 2019; Kerksick et al., 2017; Thomas et al., 2016).

Two factors influencing the effect of low carbohydrate diets on endurance performance appear to be the length of adaptation and the duration and intensity of the event. Short-term low carbohydrate diets of one to four days lead to impaired glycogen storage (Galbo et al., 1979), which can cause substantial decreases in exercise performance [Galbo et al. (1979);13]. However, even with as little as five days of implementing low carbohydrate diets, increased fat oxidation rates have been reported (Burke et al., 2021; Burke & Hawley, 2002; Goedecke et al., 1999). While this increase in fat oxidation is a consistent finding among most studies investigating the effect of low carbohydrate diets in endurance athletes (Burke et al., 1985, 2017, 2020; Carey et al., 1985; Durkalec-Michalski et al., 2019; McSwiney et al., 2018; Prins et al., 2019; Shaw et al., 2019; Stepto et al., 2002; Volek et al., 2016; Zinn et al., 2017), the results regarding exercise performance are less clear.

Recent studies comparing ketogenic to habitual or mixed control diets have shown decreases (25) or no differences (26) in time to exhaustion following prolonged diet adherence. However, early studies employing a direct comparison of ketogenic and high carbohydrate diets and their effects on prolonged endurance exercise performance have produced ambiguous results (7, 12, 27, 28). Lambert et al. (1994) reported improved time to exhaustion at moderate cycling intensity (50% of peak power output) following two weeks of a ketogenic compared with a high carbohydrate diet, but not at high intensity (85 % of peak power output). Similarly, Burke et al. (1985) reported no difference in 7 kJ/kg time trial performance immediately following 120 min of steady state cycling at 70% of VO_2max after a five-day low carbohydrate diet (2.4 g/kg/day carbohydrate; 4 g/kg/day fat) with one-day carbohydrate restoration compared with an isoenergetic high carbohydrate diet (9.6 g/kg/day carbohydrate; 0.7 g/kg/day fat). Prins et al. (23) compared the effects of 42-day ketogenic and high-carbohydrate diets on 5 km running performance at four separate points of each diet. They reported that running time was significantly faster during high carbohydrate (60–65% carbohydrate; 20% fat) when compared with the ketogenic diet (< 50 g/day carbohydrate; 75-80% fat) on day four of each diet, but not at any other point during the diets. This again indicates that exercise performance might be maintained at higher intensities. However, in a more recent study, Burke et al. (19) compared the effect of a 3-week high carbohydrate diet (8.6 g/kg/day carbohydrate; 1.2 g/kg/day fat), a periodized carbohydrate diet (8.3 g/kg/day carbohydrate; 1.2 g/kg/day fat), and a ketogenic diet (< 50 g/day carbohydrate; 4.7 g/kg/day fat) on 10 km race-walking performance; they found that race time improved significantly in the high carbohydrate and periodized carbohydrate groups, but remained unchanged in the ketogenic diet group. A recent replication study (20) produced similar results. Additionally, Burke et al. (16, 19, 20) have elucidated a potential mechanism for performance impairment following a ketogenic diet at higher intensities; specifically, they showed that exercise economy is reduced following a ketogenic compared to high carbohydrate and periodized carbohydrate diets.

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2. Methods

(a) Greek

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(b) Superscript

You can give Superscript^1 or Subscript$_2$

(c) Quotes and Block Quotes

> This can easily be done
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(d) Links

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A [linked phrase][id].
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At the bottom of the document:

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[id]: http://example.com/ "Title"
```

(e) Images

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![alt text][id]
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(f) Math

Fortunately the math formulas do not differ too much for HTML and PDF documents. For inline math a single `$` is necessary while `$$` creates formula on its own line.

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3. Results

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Table 1:Example.

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Note.
x = note 1; y = note 2.

4. Discussion

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(a) Conclusion

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5. Additional Information

(a) Data Accessibility

Data is available via a ....

(b) Author Contributions

- Contributed to conception and design:
- Contributed to acquisition of data:
- Contributed to analysis and interpretation of data:
- Drafted and/or revised the article:
- Approved the submitted version for publication:

(c) Conflict of Interest

Authors have no conflicts of interest to declare.

(d) Funding

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(e) Acknowledgments

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(f) Preprint

The pre-publication version of this manuscript can be found on SportRxiv (DOI: XXXXXXXXXX).

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