Carbohydrates and Exercise Performance: Is low the way to go, or the way to bonk?

Building Healthy Lifestyles Conference
March 18, 2016

Glenn Gaesser, PhD
School of Nutrition and Health Promotion
Arizona State University

Energy Stores in Human Body

- Fat stores = 80,000+ kcal
- Liver & muscle glycogen = ~2,000 kcal

Bonking (Hitting the “Wall”)

Why?

“Consider the muscle-glycogen bonk, where the brain works fine but the legs up and quit. Then there’s the blood-glucose bonk, where the legs work fine but the brain up and quits. Let’s not forget the everything bonk, a sorry stewpot of dehydration, training errors, gastric problems, and nutrition gaffes.”

Runner’s World, 3/1/2004

And then there’s the little-purple-men bonk. "After about 20-K, I started to see little purple men running up and down the sides of these cliffs,” says Mark Tarnopolsky, M.D., who wears hats as both a leading sports nutrition researcher and an endurance athlete. "I knew it was an hallucination, but I stopped in the middle of the race to look at them anyway,” he says. “It was kind of crazy.”

Runner’s World, 3/1/2004
Energy Production 101

**Carbohydrates**
- Fast
- Slow
- ATP synthesis via oxidative phosphorylation

**Fats**
- ATP synthesis via oxidative phosphorylation

Maximum Rates of Energy Production from Carbohydrates and Fats

Gaesser, Agro Food Industry Hi-Tech,

Crossover Concept in Fuel Utilization

Most competitive endurance athletes are at >70% VO2max during high-intensity training and during competitive races. 

**CHO is the dominant fuel**


Muscle Glycogen Use Increases Dramatically as Exercise Intensity Increases

Because fat burns more slowly than carbohydrates, muscle glycogen (the major stored form of carbohydrate in the body) use is essential to sustain high-intensity exercise.

Especially important for:
- Sudden increases in pace
- The sprint at the end of the race


Exercise Intensity and Glycogen Utilization

**Glycogen Utilization in Working Muscle**

Only at very low to moderate exercise intensities is the rate of muscle glycogen use so low that consuming a low carbohydrate diet would not matter.

Garrow and Grisham, Biochemistry, 3rd edition, 2004, p. 772

Muscle Glycogen Use is High Even in Intermittent Efforts

Soccer, football, lacrosse and other “team” sports are not steady state athletic efforts. Still, athletes use a great deal of stored glycogen.

Agnew, Sport Physiol Report Number 7 (Swedish) Trygg-Hansa, Stockholm, 1970
Muscle Glycogen and Time to Exhaustion

Athletes on high carbohydrate diets store more muscle glycogen.

The greater the amount of muscle glycogen the longer the time to exhaustion when exercising.


Muscle Glycogen Replenishment During Consecutive Days of Hard Exercise High-Carb vs. Low-Carb Diet


Classic CHO Loading “Supercompensation” Regimen (~1970)

- It was initially thought that a “depletion phase” was necessary to maximize glycogen “supercompensation”
- Subsequent research indicated this is not necessary
- Excessive carbohydrate intake during the final 3 days before competition is not necessary
- Just a simple taper with moderate-to-high intake of CHO increase muscle glycogen levels by 60%.

Ahlborg, Forvarsmedicin, 1967;3:85-99

Endurance Intensities are Well Above the “Fat Burning” Zone

Achten and Jeukendrup, Nutrition, 2004;20:716-727

Summary: Carbohydrate & Exercise

Carbohydrate:
- Preferred during moderate to high intensity exercise
- Increases time to exhaustion during higher intensity exercise
- Replaces glycogen stores much faster after exercise \( \rightarrow \) faster recovery
- “FAST” fuel (releases calories faster); fat is a “SLOW” to burn fuel

Endurance Sports Require Efforts Above the Lactate Threshold (>2-5 mmol/l)

Fat oxidation falls off sharply as blood lactate concentration increases.

Low Carbohydrate Intake and Exercise: Train “Low” – Race “High”

What’s the rationale? Does it work?

The Origins of Train “Low” – Race “High”

Why all the hype?
• Anecdotal testimonials
• Popularity of the Paleo Diet
• Recent scientific evidence
• “Classic” study by Phinney et al (1983)

Closer Examination of the Study by Phinney et al

Five well-trained male cyclists consumed a ketogenic diet for four weeks

Authors’ conclusion: “These results indicate that aerobic endurance exercise by well-trained cyclists was not compromised by four weeks of ketosis”

Low Carbohydrate Did Not Improve Endurance Time

Endurance Time at 62-64% VO₂max Before And After 4 Weeks Of A Ketogenic Diet

• Yes, two subjects performed better
• But two subjects performed worse**
• And one subject performed the same

**Ironically, these two subjects increased fat oxidation the most on the ketogenic diet

And this is the most cited study as an endorsement of a ketogenic diet for endurance performance?

Phinney et al, Metabolism, 1983, 32: 769-776
Furthermore, very few endurance contests are performed at an intensity of only ~63% of VO\textsubscript{2max}.

There is no published evidence that a low-carbohydrate diet will improve endurance performance at high (race competitive) exercise intensities.

**Evidence for Carbohydrate Dependence**

Trained runners, four trials

95% of PB half-marathon time

- CFED: Carbohydrate ingestion before and during
- CFED – NA: CFED + nicotinic acid (inhibits lipolysis)
- FAST: Fasted with placebo ingestion
- FAST – NA: FAST + NA


**Protocol Overview**

Free-fatty acid and glycerol concentrations during exercise


**Carbohydrate and Fat Burned During Run**


**Distance Covered During Run**

Conclusions

• Blunting availability of free-fatty acids did not impair intense running capacity lasting ~85 minutes
• While there was a small, but obligatory use of fat, the oxidation of carbohydrate-based fuels predominates during half-marathon running.

Does the High-Carb Approach Work?

95 of the top 100 marathon performances ever recorded are by Kenyans and Ethiopians

Macronutrient Intake of the World’s Best Marathoners

<table>
<thead>
<tr>
<th></th>
<th>Carbohydrate (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenyans</td>
<td>76.5</td>
<td>13.4</td>
<td>10.1</td>
</tr>
<tr>
<td>Ethiopians</td>
<td>64.3</td>
<td>23.3</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Onywera et al, Int J Sport Nutr Exerc Metab, 2004;14:709-719

Can a modified strategy, using both “low-carb” and “normal/high-carb” dietary practices, enhance performance?

Train “Low” – Race “High”

The Science

Scientific evidence is limited to a handful of short-term studies with this design:
Two groups of athletes, randomized to two training conditions, both receiving the same daily carbohydrate intake:
• “Train high”: 1 training session per day
• “Train low”: 2 training sessions per day, alternating days, with no carbohydrate repletion between sessions on the same day (i.e., the second training session is performed under “low-carb” conditions)

The Results

• Better skeletal muscle adaptations under the “train low” condition
• Higher exercise tolerance and greater work performed under “train high” condition
• NO DIFFERENCE IN PERFORMANCE MEASURES
Endurance Training on Low-Carbohydrate and Grain-Based Diets: A Case Study

Purpose:
To illustrate the effects of low-carbohydrate and grain-based diets on body composition, biomarkers, athletic training, and performance in an elite triathlete


Grain-Based Diet for Endurance Athlete

Study Details:
• 34-year-old male triathlete
• Consistent training since age 15
• Two 14-day diets (5-week wash-out)
  • Atkins “induction phase”
  • Grain-based
  • All food provided

Macronutrient Composition of Each Diet

<table>
<thead>
<tr>
<th>Diet Type</th>
<th>Carbohydrate (CHO)</th>
<th>Fat</th>
<th>Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Carb Diet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain-based Diet</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Habitual Diet</td>
<td></td>
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</tbody>
</table>

Macronutrient composition of "Grain-based Diet" more closely matched "Habitual Diet"

Endurance Athlete Case Study: Low Carb vs. Grain-Based Diet

Key Results
• Athlete lost weight on the low-carb diet (3.2 kg)
• During a 5K cycle ergometer performance ride
  • Power output maintained was the same for both diets
  • Heart rate and "perceived exertion" were higher on low-carb diet
• Training impact of low-carb diet was significant:
  • 6 workouts cut short on low-carb vs. 2 on grain-based diet
  • Unplanned decrease in training intensity during 5 workouts on low-carb diet, none on grain-based diet
  • During the low-carb diet:
    • Lethargy and fatigue mentioned every day in the training log (after the third day)
    • Frequent cravings for sweets
    • Interrupted sleep
    • Persistent muscle soreness
    • Psychological difficulties

Low Carb vs. Grain-Based Diets: Conclusion

Despite very little weight loss on the low-carbohydrate diet, exercise training was more difficult. The primary observation was a disruption to scheduled training on the low-carbohydrate diet that was not observed on the grain-based diet.

High Carb Day
Low Carb Day
No Carb Day
**Potential Pitfalls of “Training Low”**

- Chronic low-carb diet may compromise ability to maintain desired training intensity
- High amounts of exercise performed in a low-carb state may increase susceptibility to illness and infection (Carbs play an important role in offsetting exercise-induced immunosuppression)
- Exercising under conditions of low-carbohydrate availability may increase protein breakdown (could impair maintenance of muscle mass)
- Exercising while limiting carbohydrate intake may impair capacity to utilize carbohydrate consumed during competition


**Practical Applications for Train “Low” – Race “High”**

- Train in a fasted state
  - Morning exercise before eating
- Two training sessions per day (no CHO replenishment after first session)
- Train “low” workouts should not be intense
- Athletes should consider caffeine ingestion and/or CHO mouth rinse on train “low” days
- Protein ingestion (20-25 grams) should be ingested before, during and/or right after a train “low” exercise session
- Training program should include sessions of training “high” that simulate competition fueling schedule


**So Why Does The Train Low/Race High Concept Persist?**

**Potential Pitfalls of Too Much Protein in the Diet (which may occur on a Paleo diet)**

A number of studies published in the past 35 years have shown that high protein intake impairs the capacity for very high-intensity exercise

**The Effects of Dietary Manipulation on Blood Acid-Base Status and the Performance of High-Intensity Exercise**

Eleven healthy men performed exercise to exhaustion under three dietary conditions:

- Control (46.2 % CHO; 39.2 % Fat; 14.1 % Protein)
- Low-Carb (10.1 % CHO; 64.5 % Fat; 25.3 % Protein)
- High-Carb (65.5 % CHO; 24.7 % Fat; 9.4 % Protein)


**Dietary Acid-Base Intake**

Exercise Time at a Fixed Workload (~100% VO2max)

Results of this study have been replicated a number of times

Take-home message:
Exercise performance at very high intensities is reduced by a low-carb diet that is relatively high in protein (> ~2 grams/kg/day)

The adverse effects of high protein intakes is likely due to increasing acid load and reducing buffering capacity of the blood

Guidelines For Fueling Before, During and After Exercise

Daily Needs for Fuel and Recovery

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Situation</th>
<th>Daily CHO targets (grams per kg body weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Low-intensity or skill-based activities</td>
<td>3-5</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate exercise program (~1 h/day)</td>
<td>5-7</td>
</tr>
<tr>
<td>High</td>
<td>Endurance program (1-3 h/day of moderate-to-vigorous activity)</td>
<td>6-10</td>
</tr>
<tr>
<td>Very High</td>
<td>Extreme commitment (&gt;4-5 h/day of moderate-to-vigorous activity)</td>
<td>8-12</td>
</tr>
</tbody>
</table>

Acute fueling Strategies

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Situation</th>
<th>CHO targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>General fueling</td>
<td>Preparation for events &lt; 90 min</td>
<td>7-12 g/kg per 24 h</td>
</tr>
<tr>
<td>Carbohydrate loading</td>
<td>Preparation for events &gt; 90 min (sustained or intermittent)</td>
<td>10-12 g/kg per 24 h for 36-48 h</td>
</tr>
<tr>
<td>Speedy refueling</td>
<td>&lt; 8 h recovery between two demanding sessions</td>
<td>1.0-1.2 g/kg/h for first 4 h, then resume daily fuel needs</td>
</tr>
</tbody>
</table>

Acute fueling Strategies (continued)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Situation</th>
<th>CHO targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-event fueling</td>
<td>Before exercise &gt; 60 min</td>
<td>1-4 g/kg consumed 1-4 h before exercise</td>
</tr>
<tr>
<td>During brief exercise</td>
<td>&lt; 45 min</td>
<td>Not necessary</td>
</tr>
<tr>
<td>During sustained high-intensity exercise</td>
<td>45 – 75 min</td>
<td>Small amounts including mouth rinse</td>
</tr>
</tbody>
</table>
**Acute fueling Strategies (continued)**

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Situation</th>
<th>CHO targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>During endurance exercise (including “stop and start” sports)</td>
<td>1.0 – 1.5 h</td>
<td>30-60 g/hour</td>
</tr>
<tr>
<td>During ultra-endurance exercise</td>
<td>&gt; 2.5 – 3.0 h</td>
<td>Up to 90 g/hour</td>
</tr>
</tbody>
</table>


**Body Weight Does Not Affect Oxidation Rate of CHO Intake During Exercise**


**Summary Points and Comments**

**Endurance Performance**

- Carbohydrate is a “faster” fuel than fat
  - Faster rate of breakdown to CO₂ and H₂O
  - More energy (ATP) can be produced in a given amount of time (i.e., per minute)
- Carbohydrates are essential for high-intensity exercise
  - Carbohydrates provide more energy (ATP) per liter of oxygen consumed
  - Maximum rate of energy production is ~3-5 times higher from CHO compared to fat

**Summary Points and Comments**

**Endurance Performance**

- Initial muscle glycogen levels are important for endurance sports lasting >90 minutes
- There is no evidence to show that a low-carbohydrate diet will improve competitive endurance sport performance by more than a moderate-to-high CHO diet
- Low-carb diets may impair an athlete’s capacity for performing and completing high-intensity workouts
- High-protein content of some low-carb diets may reduce tolerance for high-intensity and maximal exercise

**Summary Points and Comments**

**Endurance Performance**

- Train “low” – race “high” method
  - Skeletal muscle adaptations are enhanced
  - But actual endurance performance has not been shown to be improved
- Even with train “low” – race “high” there is a need for adequate CHO
- The world’s best marathoners consume high-carbohydrate diets (>60%).