Coingestion of Carbohydrate-Protein During Endurance Exercise: Influence on Performance and Recovery

Michael J. Saunders

Endurance athletes commonly consume carbohydrate-electrolyte sports beverages during prolonged events. The benefits of this strategy are numerous—sports-beverage consumption during exercise can delay dehydration, maintain blood glucose levels, and potentially attenuate muscle glycogen depletion and central fatigue. Thus, it is generally agreed that carbohydrate-electrolyte beverages can improve endurance performance. A controversy has recently emerged regarding the potential role of protein in sports beverages. At least 3 recent studies have reported that carbohydrate-protein ingestion improves endurance performance to a greater extent than carbohydrate alone. In addition, carbohydrate-protein ingestion has been associated with reductions in markers of muscle damage and improved postexercise recovery. Although many of these muscle damage and recovery studies examined postexercise nutritional intake, recent evidence suggests that these benefits may be elicited with carbohydrate-protein consumption during exercise. These findings are intriguing and suggest that the importance of protein for endurance athletes has been underappreciated. However, 2 studies recently reported no differences in endurance performance between carbohydrate and carbohydrate-protein beverages. The varied outcomes may have been influenced by a number of methodological differences, including the amounts and types of carbohydrate or protein in the beverages, the exercise protocols, and the relative statistical power of the studies. In addition, although there are plausible mechanisms that could explain the ergogenic effects of carbohydrate-protein beverages, they remain relatively untested. This review examines the existing research regarding the efficacy of carbohydrate-protein consumption during endurance exercise. Limitations of the existing research are addressed, as well as potential areas for future study.

Key Words: exercise metabolism, sport nutrition, muscle damage

Sports nutrition is a complex concept, with characteristics that are unique to each sporting event and each athlete. Although most athletes can satisfy their nutritional requirements before and/or after exercise, long-duration activities require that participants also address their nutritional needs during exercise. Endurance exercise promotes vast increases in energy utilization, with significant increases in carbohydrate and fat oxidation rates (6, 16). Sizable losses of fluid and electrolytes...
from sweat may also occur, particularly during prolonged exercise in the heat (2, 9, 45). As a result, inadequate fluid and nutrient intake during endurance exercise can lead to dehydration, hyponatremia, glycogen depletion, hypoglycemia, and impaired performance. In addition, nutritional deficiencies during prolonged activity may limit the capacity for rapid recovery after exercise, which may affect subsequent performance. Numerous studies have investigated nutritional approaches to minimize these issues, resulting in various nutritional strategies that elicit positive effects for endurance athletes. Perhaps the most common of these strategies is the consumption of sports beverages containing carbohydrate and electrolytes. It is generally agreed that carbohydrate-electrolyte beverages are effective in promoting fluid balance and euglycemia and augmenting performance during prolonged endurance activities (13, 15, 29, 56). Typical guidelines suggest ingesting sports beverages with 4–8% carbohydrate at regular intervals during exercise to provide approximately 600–1400 mL of fluid and 30–60 g of carbohydrate per hour (1, 11, 13, 15). Numerous review articles have been published on the topic of carbohydrate-electrolyte beverages, and summaries from Coggan and Coyle (13) and Jeukendrup (29) are recommended reading.

A recent controversy has emerged regarding the potential role of protein in sports beverages for endurance athletes. Specifically, does the coingestion of carbohydrate-protein during endurance exercise provide benefits for performance and recovery? In this review, we discuss recent research regarding the efficacy of carbohydrate-protein ingestion during exercise. In addition, we address current limitations and methodological issues in the current literature.

**Effects of Carbohydrate-Protein Ingestion on Endurance Performance**

At least 3 recently published studies have reported significant improvements in endurance when protein is coingested with carbohydrate during prolonged exercise. In the first of these studies, Ivy et al. (25) compared the effects of a carbohydrate-protein beverage (CHO+Pro) versus carbohydrate-only (CHO) and placebo beverages. To assess endurance performance, these investigators measured cycling time to exhaustion at 85% VO2peak after 180 min of varied-intensity, submaximal cycling, which was designed to simulate the variations in intensity typically observed during competitive cycling events. Subjects received 200 mL of beverage immediately before exercise and 200 mL every 20 min during exercise, resulting in approximately 600 mL of fluid, 47 g carbohydrate, and 12 g whey protein (if present) per hour during exercise. Cyclists rode significantly longer (36%) in the time-to-exhaustion segment of the CHO+Pro trial (26.9 ± 4.5 min) than the CHO trial (19.7 ± 4.6 min), with both sports beverages outperforming a placebo (12.7 ± 3.1 min).

In a similar study in our laboratory, we compared endurance performance between CHO+Pro and CHO beverages in male cyclists during a ride to exhaustion at 75% VO2peak (48). Beverages were provided at 15-min intervals throughout the trial, with subjects consuming approximately 508 mL of fluid, 37 g carbohydrate, and 9 g whey protein per hour. Cyclists rode 106.3 ± 45.2 min when receiving the CHO+Pro beverage, compared with 82.3 ± 32.6 min with the CHO beverage, a 29% improvement in endurance. In a subsequent study, we used a similar protocol
in a mixed group of male and female cyclists while providing CHO+Pro and CHO gels (approximately 41 g carbohydrate, 10 g whey protein, plus 560 mL water per hour) during the rides (49). Athletes performed 13% longer at 75% \( V_{\text{O}_2\text{peak}} \) when receiving the CHO+P gel than with the CHO gel. In addition, these benefits were observed consistently among the subsets of men (114.8 ± 26.2 vs. 101.8 ± 24.6 min) and women (119.6 ± 34.9 vs. 104.4 ± 28.6 min).

A recent study from Van Essen and Gibala (58) examined 80-km time-trial performance between CHO and CHO+Pro beverages, in which 1000 mL of fluid, 60 g carbohydrate, and 20 g of protein were provided per hour. In contrast to the previously mentioned studies, these investigators observed no significant differences in performance between CHO+Pro (135 ± 9 min) and CHO (135 ± 9 min) treatments, although both beverages outperformed a placebo beverage (141 ± 10 min). In addition, time splits for each 20-km segment of the trials were not significantly different between CHO+Pro and CHO beverages.

### Limitations of Existing Studies of Endurance Performance

The observation of prolonged time to exhaustion in the studies by Ivy et al. (25) and Saunders et al. (48, 49) suggests a strong potential for ergogenic effects with carbohydrate-protein beverages. However, as demonstrated by Van Essen and Gibala
improved endurance performance has not been universally observed with carbohydrate-protein ingestion. Thus, questions remain regarding the conditions under which the presence of protein in a sports beverage may improve performance. In particular, the following factors may mediate the ergogenic influence of protein in sports beverages and remain to be clarified by further research.

**Amount of Carbohydrate in the Beverage**

Previous studies reporting performance improvements with CHO+Pro ingestion matched treatment beverages for carbohydrate content, resulting in higher total caloric content in CHO+Pro beverages (25, 48, 49). This suggests that adding protein to a typical CHO sports drink can improve endurance performance. The concentrations of carbohydrate in these studies were within proposed optimal ranges for sports beverages (6–8% by volume), and beverage consumption rates were at or above levels typically consumed by competitive athletes (45). However, CHO ingestion rates (37–47 g/h) were lower than peak oxidation rates for exogenous carbohydrate, which are approximately 60–72 g/h, depending on the carbohydrate types used in the beverage (26, 27, 28, 30). As a result, it is difficult to determine whether differences in performance with CHO+Pro beverages were specifically protein mediated or calorically mediated. A recent study from our laboratory reported no differences in time to exhaustion between CHO and CHO+Pro beverages matched for total calories (47). However, to match total calories between beverages, the CHO beverage contained approximately 56 g/h of carbohydrate, compared with 45 g/h for the CHO+Pro beverage. The lack of performance differences between beverages in this study suggests that the additional availability of calories in previous studies may be a factor in the improved performance with CHO+Pro beverages. It seems unlikely, however, that such a small difference in calories could explain the comparatively large differences in performance that have been reported, and the findings of Romano-Ely et al. (47) could alternatively support a protein-mediated benefit of CHO+Pro ingestion, because performance in the CHO+Pro trial equaled the CHO trial, despite 20% lower carbohydrate content in the CHO+Pro beverage.

At a minimum, results of the studies just described suggest that the impact of protein ingestion on exercise metabolism may have been historically underappreciated. More important, there is evidence that CHO+Pro beverages improve performance to an extent beyond the highest levels possible from CHO beverages. This hypothesis is supported by unpublished observations from our laboratory. In one investigation, we observed significant improvements in late-race time-trial performance with CHO+Pro versus CHO ingestion, despite carbohydrate content approximating peak oxidation levels (~60 g/h) in both beverages (50). In addition, we recently observed significant improvements in endurance when 7 g/h of a casein hydrolysate were added to a CHO beverage, with no further benefits with 14 g/h of protein, despite total carbohydrate and protein intake below 50 g/h in all beverages (42). Collectively, these findings suggest that the performance benefits with CHO+Pro ingestion are at least partially related to a protein-specific mechanism, which may not be elicited with additional calories from carbohydrates alone.

To address the limitations associated with subpeak carbohydrate intakes, it would be desirable to compare multiple CHO and CHO+Pro beverages in which
Coingestion of Carbohydrate-Protein

varying amounts of carbohydrate were compared at levels above peak exogenous oxidation levels. In this approach, CHO and CHO+Pro beverages matched for calories and carbohydrate could be compared within the same study. Although this design has benefits for separating caloric and protein differences, it has practical limitations because of the protracted study length (i.e., a minimum of 4 trials per subject). The prolonged study duration increases measurement error resulting from potential variations in motivational factors and training status of subjects, making it difficult to ascertain differences between treatments without large sample sizes. For example, we recently compared sports beverages that were matched at or above peak exogenous carbohydrate oxidation levels, hypothesizing that time to fatigue would vary between treatments as follows: Placebo < CHO (78 g/h) = CHO (97 g/h) < CHO+Pro (78 + 19 g/h). Although the hypothesized order occurred, we did not observe a statistically significant difference in performance for the CHO+Pro beverage versus the CHO beverages, despite a mean improvement of approximately 6%, possibly because of error variance that was compounded by the relatively long 4-trial protocol (unpublished observations).

There are other practical problems with comparing sports beverages at such high carbohydrate levels. These levels of fluid and substrate intake are far higher than levels voluntarily consumed by athletes (45), which may limit the application of these studies to athletic conditions. In addition, beverage ingestion rates >1 L/h are associated with gastrointestinal discomfort in some subjects (7, 41, 45). Gastrointestinal problems may cause some subjects to lower their exercise intensity or cease exercise before glycogen depletion, which is typically induced by long time-to-exhaustion and time-trial protocols (3). This could minimize the putative benefits of CHO+Pro ingestion, because protein oxidation is heightened in late exercise when glycogen levels are depleted (59, 65). Nonetheless, it is important that these types of studies be conducted to better define the mechanisms by which CHO+Pro ingestion may affect exercise metabolism and endurance performance.

**Exercise Protocols and Statistical Limitations**

Carbohydrate and CHO+Pro beverages have been compared using time-to-exhaustion (25, 47, 48, 49) and long-duration time trials (58). For the purposes of investigating sports-beverage efficacy, these protocols have relative strengths and weaknesses. For example, Jeukendrup et al. (31) observed that time-to-exhaustion protocols may evoke relatively high measurement error, reporting a coefficient of variation of >25% over 5 repeated trials. The treatment effects between beverages would need to be quite large to overcome this error variance (33), as we observed in the 4-trial protocol discussed previously. Numerous studies, however, have effectively used time-to-exhaustion protocols to demonstrate differences between CHO and placebo beverages (17, 57, 67, 70), as well as CHO+Pro beverages (25, 48, 49). This may be because fatigue during prolonged exercise of moderate intensity (i.e., 60–80% \( \text{VO}_{2\text{peak}} \)) is highly related to glycogen depletion (3). Thus, this protocol may evoke large effects when comparing treatments that are expected to influence muscle glycogen depletion and other metabolic aspects of fatigue, a characteristic that is beneficial in studies for which it is difficult to recruit large samples.

Long-duration time-trials can also be used to assess endurance performance. Time trials likely exhibit lower error variance between repeated trials (31), and
it is often argued that they may be more representative of performance in some endurance sports such as distance running and cycling (55). However, the relative differences reported between nutritional treatments are typically smaller when using time trials versus time-to-exhaustion protocols, perhaps because time-trial performance is less closely linked to glycogen depletion. To detect potentially smaller differences between treatments with adequate statistical power, it may therefore be necessary to recruit much larger samples, unless time-trial protocols are modified to assess more subtle differences in performance.

The issue just described suggests a potential limitation in the findings of Van Essen and Gibala (58), who reported no differences in time-trial performance between cyclists receiving CHO and CHO+Pro beverages. The study reported overall 80-km performance and time splits for each 20-km segment of the trial. Data were not reported for the latest stages of exercise, however, which could have increased the sensitivity to detect changes in late-exercise performance, when the potential benefits of CHO+Pro would be most apparent. When this protocol was combined with a small sample (10 subjects), the study lacked adequate statistical power to detect potential differences in performance between treatments. With 10 subjects, the statistical power to detect a 2-min difference in 80-km performance (a large “practical effect”) is estimated to be 0.32 (35), far lower than the 0.80 recommended by most scientific journals (based on means and standard deviations from the previously described study and estimating an ICC between repeated time-trial measurements of 0.9).

In an attempt to address these issues, in our laboratory we recently compared cycling performance between CHO and CHO+Pro beverages matched for carbohydrate levels at ~60 g CHO/h (unpublished observations). Each trial consisted of 3 laps of a hilly 20-km course, which concluded with a demanding 5-km climb on each lap, simulated on a computerized ergometer. Performance times were

<table>
<thead>
<tr>
<th>Study</th>
<th>Endurance-performance protocol</th>
<th>Sig. effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivy et al. (2003)</td>
<td>TTE at 85% VO_{2peak} after 180 min varied-intensity cycling</td>
<td>Y</td>
</tr>
<tr>
<td>Saunders et al. (2004)</td>
<td>TTE at 75% VO_{2peak}</td>
<td>Y</td>
</tr>
<tr>
<td>Van Essen &amp; Gibala (2006)</td>
<td>Simulated 80-km TT with timed splits for 20-km intervals</td>
<td>N</td>
</tr>
<tr>
<td>Romano-Ely et al. (2006)</td>
<td>TTE at 70% VO_{2peak}</td>
<td>N</td>
</tr>
<tr>
<td>Saunders et al. (2006)#</td>
<td>Simulated hilly 60-km TT with timed splits for 20-km intervals + final 5-km climb</td>
<td>Y</td>
</tr>
<tr>
<td>Saunders et al. (2007)</td>
<td>TTE at 75% VO_{2peak}</td>
<td>Y</td>
</tr>
<tr>
<td>Moore et al. (2007)#</td>
<td>TTE at completion of a simulated duathlon (8-km run, 50-km cycle, TTE run at 75% VO_{2peak})</td>
<td>Y</td>
</tr>
</tbody>
</table>

TTE indicates time to exhaustion. Data from published manuscripts and 2 abstracts (#) reporting unpublished work from the authors’ laboratory.
compared between beverages over the entire trial, the final 20 km, and the final 5-km climb, because we believed that the late-exercise measurements would provide greater sensitivity to detect treatment differences. Mean 60-km times were only slightly faster for the CHO+Pro beverage (mean = 0.8 min; N.S.), but most of the time difference between treatments occurred during the final 5-km climb, resulting in significantly faster times (3%) and higher power output (5%) during late exercise (50). These data may explain the differences between findings from Van Essen and Gibala (58) and studies reporting improved performance with CHO+Pro ingestion during time-to-exhaustion protocols (25, 48, 49). Perhaps more important, they demonstrate the importance of adequate statistical power when using time-trial comparisons between treatments. Because of the potentially smaller effects between treatments using this type of protocol (i.e., 3% difference in late-exercise performance compared with 13–36% in time-to-exhaustion studies) it is important for those investigating the efficacy of CHO+Pro interventions to use protocols that maximize the ability to detect performance differences or use adequately large samples to observe more subtle differences in performance time trials.

Protein Types and Amounts

To clearly understand the role of protein ingestion during exercise, further research is required to determine optimal types and amounts of protein. Blomstrand et al. (4, 5) reported in the early 1990s that endurance activity and mental performance may be enhanced with ingestion of branched-chain amino acids (BCAAs). The designs of these studies were questioned, however, and subsequent studies reported no improvements in performance with BCAA administration (38, 60, 62, 63). In addition, some investigators reported that BCAA ingestion induced some negative metabolic effects such as increased plasma ammonia levels (37, 38, 60). Colombani et al. (12) compared the metabolic consequences of consuming CHO and CHO+Pro, using a milk-protein hydrolysate, during marathon running. They observed increased plasma amino acid levels during marathon running with CHO+Pro supplementation without alterations in plasma NH₃ levels. Based on these findings, they proposed that the metabolic benefits of supplementation of whole proteins or balanced profiles of amino acids may be superior to supplementation of BCAA, because of the presence of NH₃-binding amino acids such as glutamate, alanine, and glutamine in the CHO+Pro beverage (12).

In support of this concept, all published studies reporting improved endurance performance with CHO+Pro ingestion have used whey protein (25, 48, 49). In addition, 2 recent studies from our laboratory have reported similar performance benefits when casein hydrolysate was added to CHO beverages (42, 50). We are aware of no studies that have directly compared measures of endurance performance between CHO beverages containing different protein types.

In addition to optimal protein type being unknown, it is unclear how much protein elicits the greatest response. Determining optimal protein levels is a difficult endeavor, because protein likely interacts with numerous aspects of beverage composition, such as the carbohydrate content of the beverage, total volume of beverage ingested, protein type, osmolality, individual tolerances, and so on. However, because carbohydrate is the major source of energy during competitive endurance
sports, it seems reasonable to assume that protein content should be considerably less than the carbohydrate content of sports beverages (which is typically 6–10% by volume). In published studies that have demonstrated an ergogenic effect with CHO+Pro ingestion (25, 48, 49), protein has consisted of 20% of total calories of the beverage, at levels ≤2% by volume. As a result of differing fluid ingestion rates in these studies, protein intakes varied from 9.25 to 11.75 g/h. In the studies previously mentioned (42, 50), improved endurance performance was observed with protein or protein hydrolysate intake levels that varied from 15% to 33% of calories in the beverage, at approximately 1–2% by volume. It is currently unknown whether there is a threshold level of protein intake required for performance benefits or whether diminishing returns are observed with high protein contents.

In an unpublished study, we recently compared endurance performance between CHO+Pro beverages of varying casein protein hydrolysate content during a simulated duathlon. Subjects performed 3 trials consisting of an 8-km run, 50-km cycle, and second run (to exhaustion) while consuming 1500 mL of a 6% carbohydrate beverage during the cycling portion of the event. Each trial varied in the amount of protein provided during the trial (0, 10, or 20 g/L). Time to exhaustion during the second run was significantly longer in the CHO+Pro trials than the CHO trial, with no differences between 10 and 20 g/L CHO+Pro trials (42). Although not statistically significant, the mean for the 20-g/L protein trial was lower than the 10-g/L protein trial, suggesting an upper limit for the optimal protein content of CHO+Pro beverages. The protein content of the CHO+Pro beverage in the study by Van Essen and Gibala (58) was also 20 g/L (33% of total calories). When combined with the high rate of fluid ingestion in that study, it is possible that the relatively high rate of protein intake (20 g/h) exceeded the optimal dose for benefits in endurance performance, because all aforementioned studies demonstrating a performance improvement used protein ingestion rates of approximately 7–18 g/h (25, 42, 48, 49, 50).

**Physiological Mechanisms for Improved Performance**

Although there is growing evidence that CHO+Pro ingestion may improve endurance performance, a consensus on this topic will not be possible until future studies provide direct mechanisms to explain the reported performance improvements. Although currently speculative, there are numerous potential mechanisms that could plausibly contribute to the ergogenic effects of CHO+Pro ingestion. These mechanisms should be carefully examined in subsequent studies of CHO+Pro ingestion during exercise.

Compared with carbohydrates and fats, protein provides a relatively small contribution to energy production during endurance exercise, perhaps 5–10% of total energy demands (6, 20). However, this proportion may increase when exercise is performed in a glycogen-depleted state, as occurs during the late stages of endurance exercise (34, 59, 65). Recent studies have shown that CHO+Pro ingested during endurance exercise can increase protein oxidation. For example, Koopman et al. (32) reported that CHO+Pro ingestion during prolonged exercise resulted in 2-fold increases in protein oxidation compared with CHO. Increased protein oxidation with CHO+Pro ingestion could alter substrate utilization and potentially spare blood glucose and/or muscle glycogen late in exercise, although this hypothesis remains to be tested.
Table 2 Comparison of Beverage Characteristics in Endurance-Performance Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Fluid/h (mL)</th>
<th>Beverage</th>
<th>CHO/h (g)</th>
<th>Protein/h (g)</th>
<th>Protein type</th>
<th>Sig. effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivy et al. (2003)</td>
<td>600</td>
<td>CHO</td>
<td>47</td>
<td>0</td>
<td>Whey concentrate</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>47</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saunders et al. (2004)</td>
<td>508</td>
<td>CHO</td>
<td>37</td>
<td>0</td>
<td>Whey concentrate</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>37</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van Essen &amp; Gibala (2006)</td>
<td>1000</td>
<td>CHO</td>
<td>60</td>
<td>0</td>
<td>Whey isolate</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>60</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romano-Ely et al. (2006)</td>
<td>600</td>
<td>CHO</td>
<td>56</td>
<td>0</td>
<td>Whey concentrate</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>45</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saunders et al. (2006)#</td>
<td>1000</td>
<td>CHO</td>
<td>60</td>
<td>0</td>
<td>Casein hydrolysate</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>60</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saunders et al. (2007)</td>
<td>560</td>
<td>CHO</td>
<td>41</td>
<td>0</td>
<td>Whey concentrate</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro</td>
<td>41</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moore et al. (2007)#</td>
<td>577</td>
<td>CHO</td>
<td>35</td>
<td>0</td>
<td>Casein hydrolysate</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro (1%)</td>
<td>35</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CHO+Pro (2%)</td>
<td>35</td>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data from published manuscripts and 2 abstracts (#) reporting unpublished work from the authors’ laboratory.
It is also possible that CHO+Pro ingestion sustains high rates of aerobic metabolism by influencing tricarboxylic acid (TCA) -cycle intermediates. TCA-cycle flux can increase more than 80-fold during exercise, and a number of amino acids play integral roles in anaplerotic processes (66). The TCA cycle undergoes a carbon drain during prolonged moderate-intensity exercise, perhaps as a result of progressive increases in leucine oxidation that coincide with glycogen depletion (66). This decline in TCA-cycle intermediates appears related to impaired ability to meet the demands for ATP production (22, 64, 66). If CHO+Pro ingestion can offset the decreases in TCA-cycle intermediates during prolonged exercise, this mechanism could explain the observed improvements in time-to-exhaustion and late-exercise time-trial performance.

The ergogenic effects of CHO+Pro could also be influenced by protein’s potential effect on central fatigue. The ratio of free tryptophan (f-TRP) to BCAA increases during exercise, causing increased brain serotonin levels and potentially leading to the onset of fatigue during endurance exercise (10, 18, 43). CHO+Pro ingestion during exercise could potentially influence both aspects of this ratio in a positive manner. Carbohydrate ingestion has been shown to attenuate changes in f-TRP levels during exercise (19), which may reduce central fatigue with carbohydrate intake during exercise. A recent study reported improvements in endurance performance when a carbohydrate mouth rinse was used (8). Because of the relatively short duration of the exercise trial (<1 h) and the removal of carbohydrate from the mouth before digestion, it seems possible that improved performance may have been due to reduced central inhibition associated with oral-carbohydrate receptors rather than via the typically assumed metabolic mechanisms. Although speculative, it is possible that CHO+Pro ingestion augments the proposed effects of carbohydrate on central fatigue via similar mechanisms, which could partially explain the observed effects of CHO+Pro on endurance performance.

It is also possible that protein aids endurance performance by facilitating faster fluid/fuel transport across the lining of the intestine. Amino acids have multiple transport pathways from the intestines (53) and stimulate fluid and electrolyte absorption via mechanisms that are unique from glucose (23). Thus, it is possible that adding protein to sports beverages may produce synergistic effects with carbohydrates that improve carbohydrate, electrolyte, and fluid uptake and utilization. In a comparable concept, mixtures of multiple carbohydrate sources have been shown to elicit higher levels of exogenous carbohydrate oxidation during exercise through the use of differing absorptive pathways for individual carbohydrate types (26, 27, 28). Similarly, adding protein to CHO beverages could facilitate greater total oxidative capacity, either via increased exogenous protein oxidation or via interactions that influence other forms of substrate utilization. The potential influence of CHO+Pro ingestion on fluid uptake and retention may also have implications for endurance performance, because a few recent studies have suggested that CHO+Pro beverages have hydration properties similar (12) or superior (21, 51) to CHO beverages.

Finally, the influence of CHO+Pro ingestion on insulin stimulation during exercise should potentially receive further study. Ivy et al. (25) reported elevated insulin levels with CHO+Pro ingestion compared with water, but these levels were not statistically higher than a CHO trial. Unpublished data from our lab demonstrated a very similar trend, with slightly (but not significantly) higher insulin levels
Coingestion of Carbohydrate-Protein during CHO+Pro trials than CHO trials. Additional research is required to clearly determine the effects of CHO+Pro ingestion on insulin levels at various exercise intensities and durations, although preliminary evidence suggests that this factor is unlikely to contribute significantly to the performance improvements observed with CHO+Pro beverages.

Effects of Carbohydrate-Protein Ingestion During Exercise on Recovery

The traditional role of carbohydrate-electrolyte sports beverages has been to optimize performance by delaying dehydration and hypoglycemia and potentially influencing glycogen depletion and central fatigue. However, nutrient intake during prolonged exercise may also have important implications for recovery from exercise. A growing number of studies have reported that CHO+Pro consumption during recovery from heavy exercise improves various aspects of recovery in endurance athletes. Although some of these areas of research remain controversial, numerous studies have reported that CHO+Pro ingestion may improve glycogen repletion (24, 61, 68, 71), protein balance (32), muscle-damage markers (36, 47, 48, 49), and subsequent performance (44, 48, 68). As a result, it has become fairly common practice for endurance athletes to consume CHO+Pro during recovery from exercise. However, it is less well understood how ingesting CHO+Pro during exercise influences muscle recovery.

Protein Balance

A number of studies have demonstrated that protein degradation increases during endurance exercise (32, 46, 69). Sheffield-Moore et al. (52) observed that protein breakdown was heightened immediately after moderate-intensity aerobic exercise. Although protein synthesis was also elevated from resting levels, total net protein balance remained negative for up to 3 h postexercise without nutritional intervention (52). CHO+Pro beverages may improve the balance between protein synthesis and degradation during and after exercise. Koopman et al. (32) observed that net protein balance was negative throughout 6 h of cycling/running at ~50% VO_{2max} with CHO ingestion (0.7 g CHO·kg^{-1}·h^{-1}). However, CHO+Pro ingestion (0.7 g CHO·kg^{-1}·h^{-1} + 0.25 g Pro·kg^{-1}·h^{-1}) significantly increased protein synthesis and decreased protein degradation, resulting in a positive net protein balance during and after exercise. In a study examining ingestion of CHO+Pro during recovery from resistance exercise, Miller et al. (40) observed that postexercise leg phenylalanine uptake was significantly greater after CHO+Pro administration than after CHO or protein intake alone. The authors concluded that carbohydrate-induced hyperinsulinemia was inadequate for protein synthesis after exercise without an adequate supply of amino acids. Results of the few studies completed to date suggest that this combination may also be beneficial for protein balance when CHO+Pro is consumed during endurance exercise.

Muscle Damage and Subsequent Performance

The studies discussed here suggest that recovery from exercise could be augmented by CHO+Pro ingestion during exercise. This concept is supported by a number
of recent studies that have observed attenuated markers of postexercise muscle damage with CHO+Pro ingestion. CHO+Pro has been associated with attenuated postexercise levels of plasma CK (36, 47, 48) and LDH (47) and subjective ratings of muscle soreness (21, 36, 39, 47) compared with CHO ingestion. Furthermore, these benefits have been observed in studies that compared CHO+Pro and CHO beverages that were matched for carbohydrate content (36, 39, 48) or total calories (47).

Reductions in postexercise muscle-damage markers may have important implications for subsequent exercise performance. We previously reported significant reductions in postexercise plasma CK levels after CHO+Pro ingestion, which were accompanied by improvements in subsequent endurance-exercise performance (48). However, others have reported no improvements in subsequent performance after CHO+Pro ingestion, despite reductions in postexercise plasma CK levels (36, 47). Differences in these findings may be a result of relative differences in muscle damage in these studies, because the postexercise CK response elicited during the nonprotein trial was much greater in the study reporting a significant improvement in subsequent performance (~1300 U/L) (48) than in studies showing no differences in subsequent performance (~300–580 U/L) (36, 47). This concept was supported by subsequent unpublished analyses in which we determined that subjects who incurred larger attenuations in CK with CHO+Pro ingestion experienced significantly greater improvements in subsequent performance (14). Similarly, Luden et al. (36) reported that runners completing higher weekly mileages observed the greatest attenuations in postexercise CK with CHO+Pro, perhaps because of the higher potential for damage associated with increased mileage. These higher mileage athletes also had a greater tendency for improved subsequent performance with the CHO+Pro treatment.

The data discussed here suggest that CHO+Pro ingestion may reduce markers of muscle damage in endurance athletes. These alterations may produce important effects on subsequent performance if the attenuations in muscle damage are large enough to be of practical importance for muscle function. Although these studies suggest that CHO+Pro is potentially important for recovery in endurance athletes, it is difficult to determine whether these benefits were the result of feedings provided during exercise, because the aforementioned studies provided CHO+Pro postexercise (36, 39) or both during exercise and postexercise (47, 48). However, in a recent unpublished investigation, we compared the muscle-recovery effects of a CHO+Pro beverage (78 g CHO/h + 19 g Pro/h) with those of a calorically matched CHO beverage (97 g CHO/h), carbohydrate-matched CHO beverage (78 g CHO/h), and placebo beverage (0 g CHO/h), which were provided during exercise to exhaustion. Although the beverages were provided only during exercise, the CHO+Pro treatment produced significant reductions in postexercise CK and myoglobin levels compared with all other treatments (54). In addition, muscle performance during a leg-extension test 24 h postexercise was significantly higher after the CHO+Pro trial than all other trials. Collectively, these data suggest that CHO+Pro ingestion can reduce markers of postexercise damage and potentially improve performance in subsequent exercise. In addition, it appears that these benefits can be elicited by consuming CHO+Pro beverages during exercise alone.
### Table 3 Studies Examining Muscle-Damage Markers and Subsequent Performance With CHO+Pro Ingestion

<table>
<thead>
<tr>
<th>Study</th>
<th>Beverage timing</th>
<th>Damage markers</th>
<th>↓ with CHO+Pro</th>
<th>Subsequent performance</th>
<th>Sig. effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saunders et al. (2004)</td>
<td>During/Post</td>
<td>CK</td>
<td>Y</td>
<td>TTE at 85% VO$_{2\text{peak}}$</td>
<td>Y</td>
</tr>
<tr>
<td>Millard-Stafford et al. (2005)</td>
<td>Post</td>
<td>CK</td>
<td>N</td>
<td>TTE at 90% VO$_{2\text{max}}$</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soreness</td>
<td>Y</td>
<td>5-km TT</td>
<td>N</td>
</tr>
<tr>
<td>Romano-Ely et al. (2006)</td>
<td>During/Post</td>
<td>CK</td>
<td>Y</td>
<td>TTE at 80% VO$_{2\text{peak}}$</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDH</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soreness</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Laurent et al. (2006)#</td>
<td>During</td>
<td>CK</td>
<td>Y</td>
<td>Leg-extension reps. at 70% 1-RM</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myoglobin</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soreness</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luden et al. (2007)</td>
<td>Post</td>
<td>CK</td>
<td>Y</td>
<td>5- to 8-km cross-country TT</td>
<td>N*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soreness</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TTE indicates time to exhaustion; TT time trial. Data from published manuscripts and 1 abstract (#) reporting unpublished work from the authors’ laboratory. *No significant main effect across all subjects but a significant association between the amount of CK reduction with CHO+Pro and improvements in performance.
Summary

In summary, a small but growing number of studies have reported improved endurance performance with carbohydrate-protein ingestion during exercise. However, there is controversy regarding the specific nutritional ingestion protocols and exercise conditions under which these benefits may be elicited. Further research is required to establish potential mechanisms to explain the observed benefits of carbohydrate-protein beverages on endurance performance. There also remain questions regarding optimal types and amounts of protein to be included in beverages consumed during exercise. In addition to their putative ergogenic effects on endurance performance, carbohydrate-protein beverages may have a positive influence on postexercise recovery. A number of studies have reported improved protein balance and attenuated markers of muscle damage with carbohydrate-protein ingestion during exercise. These alterations in muscle damage may have important implications for subsequent exercise performance.

References


