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REVIEW

Nutritional strategies for post-exercise recovery: a review

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Abstract

Finding the optimal nutrition regimen for enhanced recovery is fundamental in enhancing exercise training and performance. Therefore, research has aimed to examine post-exercise nutritional strategies for optimal recovery. Because muscle glycogen is the primary substrate utilised during high-intensity exercise, it must be replenished. Recent research has examined the effectiveness on recovery of adding protein to a post-exercise carbohydrate beverage. This review summarises and analyses the literature on nutritional strategies aimed at enhancing various indicators of post-exercise recovery: glycogen resynthesis, muscle damage and performance. Furthermore, the literature on Medline and Pubmed comparing the effectiveness of carbohydrate-only (CHO) beverage with a carbohydrate:protein (CHO:PRO) beverage on maximising recovery was reviewed. The methods and results of studies regarding post-exercise nutritional strategies for recovery were analysed. Primary results of this review suggest that the optimal timing in regard to post-exercise nutritional strategies for maximal glycogen resynthesis is within the first 30 minutes after exercise. The literature suggests that 1.0 - 1.5 $g.kg^{-1}h^{-1}$ of carbohydrate ingested at 2-hour intervals after exercise for up to 6 hours may be optimal for recovery. The addition of protein to a post-exercise meal may supply additional amino acids necessary for muscle repair creating an anabolic condition.

Introduction

Athletes and sports dietitians have sought post-exercise nutritional strategies that will enhance muscle glycogen resynthesis after exercise, enhance recovery and maintain or improve the quality of future workouts or performances.[1-3] Athletes may participate in one or more training sessions a day with anywhere from 6 to 24 hours of recovery between workouts.[3] A principal component of training for an elite athlete is to maximise training in order to increase potential for competition. Because full and often rapid recovery is necessary for optimal performance,[2] athletes should practise nutritional strategies that maximise recovery.

Dietary recommendations for pre-competition nutritional strategies have been well established.[1] Because muscle glycogen is the main fuel during intense exercise, replenishing muscle glycogen stores in the post-exercise recovery period is an important factor influencing recovery and performance. In addition, the timing and composition of a post-exercise meal is highly dependent upon the duration and intensity of the preceding exercise bout.[4] Research regarding post-exercise nutritional strategies has focused on timing of ingestion, type of CHO (solid v. liquid), amount of carbohydrate, presence of other nutrients (e.g. protein), and frequency of post-exercise feedings to determine the most effective way to enhance glycogen resynthesis.[5] Research examining carbohydrate consumption during recovery periods of 4 hours or more suggests enhanced recovery and exercise performance which would be beneficial to athletes competing in events with short recovery periods (preliminary heats, finals) such as track and field, swimming, and multiple day events, such as the Tour de France. Guidelines regarding the optimal timing and amount of carbohydrate after exercise have been well established.[3,4]

This article will provide an overview and discussion of the research that focuses on the effects of CHO and CHO:PRO feedings after exercise on various indices of recovery, including muscle damage, glycogen resynthesis and exercise performance. Research has also examined the effectiveness of the addition of protein to a post-exercise carbohydrate beverage on recovery. In addition, this paper will review the existing guidelines for a post-exercise recovery meal,[4] including timing and presence of other nutrients.

Carbohydrate and recovery

Muscle glycogen is the primary fuel source during high-intensity exercise and an important source during endurance exercise. Therefore, after prolonged intense exercise, post-exercise glycogen restoration plays a very important role in the recovery process. Because endogenous carbohydrate is a crucial but relatively limited fuel during high-intensity prolonged endurance exercise, it must be replenished. Post-exercise glycogen synthesis is highly dependent on the extent of glycogen depletion, as well as the type, duration and intensity of the exercise session.[6] For up to 6 hours after exercise, the rate of muscle glycogen resynthesis is accelerated, and within 24 hours after exercise complete restoration of glycogen stores can occur when sufficient amounts of carbohydrate are consumed.[1,7] Glycogen resynthesis after a glycogen-depleting exercise bout or endurance exercise occurs in two phases. The first phase, or the rapid phase,

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lasts anywhere from 30 to 60 minutes and is insulin independent due to the increased permeability of the muscle cell as a result of exercise-induced translocation of GLUT-4 (glucose transporter carrier protein-4) and plausibly an up-regulation of glycogen synthase. An increase in post-exercise glycogen synthase and exercise-induced increases in insulin sensitivity may be the potential mechanism responsible for the 2- to 4-hour period of enhanced glycogen resynthesis following exercise.

The literature indicates that a recovery meal consumed within 2 hours after exercise, compared with no feeding, is effective in improving recovery.[8] Because complete muscle glycogen resynthesis can take as long as 24 hours, even under optimal conditions, studies have examined methods to increase the rate of muscle glycogen resynthesis.[9] Depending on the extent of glycogen depletion, consuming 1.0 - 1.5 g CHO.$kg^{-1}h^{-1}$ immediately after exercise, and at 30-minute intervals for up to 6 hours after exercise, appears to be optimal for adequate glycogen resynthesis.[1,4,10,11,25] On the other hand, if CHO intake is delayed by 2 hours, glycogen resynthesis rates have been found to be 45% lower.[3,12]

Intestinal absorption of glucose is possibly a rate-limiting factor for glycogen resynthesis when a large bolus of carbohydrate is consumed after exercise.[13] CHO supplementation (~1.0 g.$kg^{-1}h^{-1}$) provided at frequent intervals (15 - 60-minute intervals) after exercise has been suggested to be more effective than a large bolus in maintaining higher blood glucose levels, thereby resulting in increased muscle glycogen restoration.[1,3]

The majority of the research has examined the effect of a post-exercise recovery beverage given in 1-hour increments. However, little research has examined the effects of providing a post-exercise beverage at more frequent intervals versus a large bolus feeding. Research regarding glycogen resynthesis rates is equivocal when different amounts of carbohydrate were consumed after exercise.[1,6] Ingesting a carbohydrate beverage at more frequent intervals (30-minute intervals) has been associated with enhanced glycogen resynthesis rates.[1,12,14] Van Loon *et al*. found that an increase in post-exercise consumption of carbohydrate from 0.8 to 1.2 g.$kg^{-1}h^{-1}$ taken at 30-minute intervals increased muscle glycogen synthesis rates (16.6 v. 35.4 mmol.kg^{-1}.dw.h^{-1}) in 8 trained cyclists following a glycogen depletion cycling trial.[6] The majority of studies that have found no effect on glycogen resynthesis with increased carbohydrate intake post exercise have supplemented at 2-hour intervals.[12,14] Recent research suggests that 2-hour intervals may not be optimal for increasing muscle glycogen resynthesis, especially since rapid resynthesis occurs within the first 2 hours after exercise.[6,15-17] Other studies have reported higher glycogen resynthesis rates when a supplement was ingested more frequently as opposed to one large bolus.[10,18]

The research shows positive results for a post-exercise bolus feeding on glycogen resynthesis, recovery and performance. However, further research is needed to determine whether a post-exercise feeding provided at more frequent time intervals during the recovery period could result in further improved performance. Discrepancies among study results may be due to the difference in

TABLE I. Summary of studies that investigated the effectiveness of a CHO-only beverage versus a CHO:PRO beverage on recovery and performance indices grouped according to year published

Author (year)	Subjects (*N*)	Protocol	Measures	Treatment	Results
Carrithers, 2000	7 male collegiate cyclists	70% max to exhaustion, overnight rest, 75 m @70% max to exhaustion & 6 x 1 m sprints	Muscle glycogen Serum GLU Serum insulin	CHO, CHO:PRO, CHO:AA Eucaloric (1 g.kg^{-1} CHO), every 30 m for 4 h	No diff. in muscle glycogen or performance
Ivy, 2002	7 trained male cyclists	2.5 h @ 70% max cycl., Tx @ 1, 2 h post-exercise	Muscle GLY Plasma insulin	CHO: PRO (80:28) LCHO (80 g) H CHO (108 g)	CHO:PRO sig. (p<0.05) higher GLY resynth
Saunders, 2004	15 trained male cyclists	75% max to exhaustion 12-15 h recovery 85% max to exhaustion	CPK performance	CHO (7.3%) & CHO:PRO (7.3%: 1.8%) Given during and post exercise	83% lower CPK in CHO:PRO, 40% longer TT (CHO:PRO)
Betts, 2005	9 (study A) 7 (study B) recreational athletes	90 min run @ 70% max to exhaustion, 4 h recovery	Run time to exhaustion @ 85% max Insulin response	9% CHO v. 9% CHO; 1.5% PRO (1.2 g.kg^{-1}.h^{-1} CHO v. 0.8 g.kg^{-1}.h^{-1})	No diff. in performance, sig. (p<0.05) Greater insulin response w CHO:PRO
Karp, 2006	9 trained male cyclists	Interval workout 4 h recovery 70% max to exhaustion	Cycling performance Total work RPE	CHOC milk, FR (Gatorade), CR (Endurox): (1 g.kg^{-1}.h^{-1} CHO) for first 2 h post exercise	TT & total work were sig. (p<0.05) greater w FR and choc milk
Berardi, 2006	6 competitive male cyclists	60 min time trial (am) 6 h recovery 60 min time trial (pm)	Muscle glycogen Time trial performance	Isocaloric (4.8 kcal.kg-1) CHO: PRO (0.8 g.kg^{-1}, 0.4 g.kg^{-1}), CHO (1.2 g.kg^{-1}), PLB for 2 h post exercise, followed by solid meal 4 h post (7 kcal.kg^{-1})	Liquid CHO:PRO (p<0.05) greater gly synthesis during recovery No diff TT
Luden, 2007	23 cross-country runners (11M, 12 F)	6 d suppl. during workout	CPK 5k & 8k soreness	CHO:PRO:A (1.4 g.kg^{-1} CHO, 0.3 g.kg^{-1} PRO, Vit C & E), CHO (1.46 g.kg^{-1}): 30 min post exercise	Sig. (p<0.05) lower CPK, & soreness in C:P:A. No diff. in performance

TT = time trial, CPK = creatine kinase, CHO = carbohydrate, PRO = protein, C:P:A = carbohydrate, protein, antioxidant, PLB = placebo.

protocols used, timing and interval of post-exercise recovery meals, training status of subjects, and form of CHO. Therefore, considering these limitations and inconsistency among the research protocols, current research suggests that 1.0 - 1.5 $g.kg^{-1}h^{-1}$ of CHO is sufficient for maximal glycogen resynthesis.[1,3,4] More studies are needed that examine the effects of a post-exercise feeding over time and that simulate a normal training programme.

Addition of protein to CHO in a recovery meal

The literature concerning the effects of post-exercise ingestion of a CHO-PRO supplement compared with a CHO supplement (i.e. sports beverage) on performance is inconsistent. Some studies show improved performance with the CHO-PRO complex versus a CHO only,[11,13,16-21] while others show no difference in performance.[5,22-24] It should be noted that the majority of the literature has examined recovery in trained cyclists or runners when performing a time trial to exhaustion at 70 - 85% of VO_{2max}.[5,11,13,16,20-24] Table I provides a summary of several studies that have investigated the effectiveness of a CHO-only beverage versus a CHO:PRO beverage on recovery indices.

Protein and muscle glycogen resynthesis

Protein contributes an estimated 5 - 15% of total energy expenditure during endurance exercise,[25] which is considerably less than the contribution of carbohydrate. Berardi *et al*. found a significant ($p<0.05$) improvement in glycogen resynthesis during a 6-hour recovery following a 60-minute cycling time trial with CHO:PRO (0.8 $g.kg^{-1}$ CHO, 0.4 $g.kg^{-1}$ PRO) in male cyclists (CHO:PRO 28.6±2.1 $mmol.l^{-1}$ v. CHO 22.2±1.1 $mmol.l^{-1}$), while Betts *et al*. found a significant ($p<0.05$) increase in insulinaemic response with CHO:PRO trial (CHO:PRO 13.5±1.1 mIU 240 $min^{-1}.ml^{-1}$ v. CHO 11.4±0.9 mIU 240 $min^{-1}.ml^{-1}$) during a 4-hour recovery after 90 minutes of running at 70% of VO_{2max} in active runners.[5,22] However, neither of these studies found a difference in performance during a run time to exhaustion at 85% of VO_{2max} [22] or a 60-minute time cycling time trial5 between the CHO:PRO and CHO-only trials. These findings are similar to other studies [6,15-17] which have reported improved glycogen repletion following post-exercise CHO-PRO supplementation (at a 2 - 2.9:1 ratio of CHO-to-protein).[1] Berardi *et al*. speculated that the self-selected intensity used in the time trial for this study may have impacted performance outcomes.[5] A controlled intensity may have been more beneficial. Betts *et al*. suggested that factors such as protein content, frequency of supplementation, and factors other than carbohydrate availability such as acidosis, which are related to fatigue, may have affected performance.[22]

These findings are similar to the earlier-reported studies indicating improved glycogen repletion following post-exercise CHO-PRO supplementation compared with CHO only,[6,15-17] while others have observed no effects. [5,9,22,23,26] Contrary to these findings, Ivy *et al*. found that consuming 200 ml of a solution with a 4:1 ratio of CHO-PRO (7.75% CHO/1.94% PRO) every 20 minutes during the recovery period enhanced cycling endurance performance by 36% in trained cyclists versus a CHO-only (7.75% CHO) solution. Reasons for these performance differences among the studies are inconclusive. However, the authors speculated that the results of this study may have been related to maintenance of plasma amino acid levels as it relates to the (branched chain amino acid) central fatigue hypothesis, sparing of muscle glycogen, or retention of Krebs' cycle intermediates.[20]

Decreased muscle glycogen levels are closely related to fatigue during exercise.[16] The addition of protein to a CHO beverage would be practically important if it further increased performance and enhanced recovery between exercise sessions with a short recovery period. Current research has examined the impact after intense exercise of adding protein (PRO) (~20% of total calories) to a carbohydrate beverage on muscle glycogen resynthesis. Prior research suggested that the addition of protein to a post-exercise carbohydrate beverage enhanced glycogen resynthesis due to an increase in insulin levels, thereby enhancing glucose deposits in the muscle.[3,6,17,23] However, it should be noted that the aforementioned investigations were not eucaloric between the beverages. Recently, when the energy content of the protein is matched in the beverages, some of these findings regarding the increase in glycogen resynthesis have been refuted.[3]

Carrithers *et al*. found no difference in muscle glycogen resynthesis rates when comparing three post-exercise eucaloric (CHO, CHO:PRO, versus a CHO:amino acid) beverages administered every 30 minutes during a 4-hour recovery in male collegiate cyclists after a glycogen depletion ride on a cycle ergometer.[23]

In contrast, Ivy *et al*. suggested that consumption of a post-exercise CHO:PRO (80 g CHO, 28 g PRO, and 6 g fat) beverage enhanced early post-exercise muscle glycogen resynthesis rates after 2.5 hours cycling at 70% of VO_{2max} when compared with a high CHO-only (108 g CHO, and 6 g fat), and low CHO-only (80 g CHO, and 6 g fat) beverage. In addition, there were no differences in post-exercise insulin concentrations among the three treatments; however, post-exercise plasma glucose concentrations were significantly lower with the CHO:PRO beverage. The authors speculated that the increase in muscle glycogen restoration and decrease in plasma glucose concentrations with a CHO:PRO beverage may signify enhanced glucose uptake and relocation of intracellular glucose disposal.[15] Furthermore, the addition of protein to a post-exercise recovery meal may be beneficial if carbohydrate consumption is below the threshold (<1$g.kg^{-1}$) for maximal glycogen replacement.[3]

Protein and muscle recovery

The addition of protein to a post-exercise recovery meal may also enhance net protein anabolism.[13] During the post-exercise period, there is an increased rate of muscle protein synthesis in trained individuals.[3] The results of literature [6,15-17] seem to be in support of the addition of protein to the recovery beverage. In addition, studies have reported decreases in muscle damage (CPK) with the addition of PRO to a recovery beverage after exercise sessions.[8,13,21,25,27,28] Both high-intensity and prolonged endurance exercise can damage skeletal muscle, resulting in delayed-onset muscle soreness with concurrent increases in markers of muscle damage such as creatine kinase (CK), myoglobin (Mb), cortisol and lactate dehydrogenase (LDH).[29,30] Elevated levels of these enzymatic markers are associated with decreased performance.[30] Due to the applied nature of recovery studies, the majority of the literature examining muscle damage has included multiple indicators of muscle damage: blood-borne creatine kinase (CK), subjective measures of muscle soreness (using a visual scale).[31] However, CK has been criticised as an effective indicator of muscle damage because of poor correlations with direct measures of muscle damage.

Research that has examined subsequent exercise performance and muscle damage suggests that a CHO:PRO v. a CHO-only beverage ingested during and after exercise may positively influence recovery.[13,21,25,32] Saunders *et al*. found that the addition of protein to a carbohydrate replacement beverage taken during and after exercise resulted in 83% lower CK levels 12 - 15 hours after endurance cycling at 85% of VO_{2max} when compared with a CHO-only beverage in trained cyclists. In addition, cyclists performed 40% longer following the consumption of a CHO:PRO beverage.[13] However, it should be noted that the amount of calories between the two beverages were not equivalent (CHO:PRO 581 kcals; CHO 391 kcals). Another study that compared the ingestion of CHO:PRO gels with CHO-only gels during and after a cycling trial at 70% of VO_{2max} to exhaustion in cyclists, found that CK levels were significantly increased (p<0.05) post exercise with the CHO-only trial ((pre) 183±116 $U.l^{-1}$, (post) 267±214 $U.l^{-1}$) compared with the combined CHO:PRO trial ((pre)180±133 $U.l^{-1}$, (post) 222±141 $U.l^{-1}$).[25] These findings are similar to a study by Romano *et al*., who found that consumption of a CHO:PRO:antioxidants (CHO:PRO:A) v. a CHO-only beverage during and after two consecutive rides to exhaustion (the first ride at 70% of VO_{2max} , followed by a second ride at 80% of VO_{2max}) significantly (p<0.05) attenuated levels of CK (CHO: (pre) 203±120 $U.l^{-1}$, (post) 582±475 $U.l^{-1}$, and CHO:PRO:A (pre) 188±119 $U.l^{-1}$ v. 273±169 $U.l^{-1}$), as well as lactate dehydrogenase (LDH), and subjective muscle soreness using a 5-point scale (CHO 3.0±5.0, and CHO:PRO:A 1.0±3.0) after exercise.[8] The two beverages used in this study were matched for caloric content. It is unclear whether decreases in muscle damage and improvements in performance would be seen with post-exercise feedings alone[31] compared with feedings given both during, and after the workout. It should be noted that subjects supplemented both during and post exercise in most aforementioned studies.

Recently, chocolate milk has been suggested to be an effective, but lower-cost recovery aid due to a CHO:PRO ratio similar to many commercial recovery and carbohydrate-replacement beverages.[11] Chocolate milk is composed of monosaccharides (glucose and fructose) and disaccharides (lactose), while the commercially available recovery beverage consists of monosaccharides (glucose and fructose) and complex carbohydrates (maltodextrin). Based on the recommendations (4) regarding post-exercise CHO intake, a 70-kg male, would need to consume 510 - 810 ml (70 - 84 g CHO, and 19 - 30 g PRO) and a 60-kg female 435 - 690 ml (60 - 72 g CHO and 16 - 26 g PRO) of low-fat chocolate milk per hour. Karp *et al*. examined the effectiveness of consuming chocolate milk (CHOC) as a post-exercise recovery aid between two cycling sessions in trained cyclists. After 4 hours of recovery, cycling time to exhaustion at 70% of VO_{2max} was significantly longer for the chocolate milk trial (by ~15 minutes) compared with the recovery beverage (Endurox R4, PacificHealth Labratories, Woodbridge, NJ) trial.[11] The differences in performance demonstrated in this study may have been attributed to the different types of carbohydrate in the beverages. Because increases in muscle glycogen levels during the early hours of recovery are greater with simple v. complex carbohydrate,[33] perhaps the 4-hour recovery period did not allow enough time for the complete digestion of the complex carbohydrates in the recovery beverage. The authors of this study also speculated whether the higher fat content of chocolate milk may have increased the levels of free fatty acids in the blood, possibly delaying glycogen depletion during the subsequent cycling trial to exhaustion and allowing subject to cycle longer.[11] However, when post-exercise consumption of CHOC was compared with an isocaloric over-the-counter recovery beverage (CRB) (based on 1 g $CHO.kg^{-1}$ of body weight/ hour post-exercise for the first 2 hours) after a high-intensity fatiguing trial, the authors found no differences in cycling time to exhaustion at 85% of VO_{2max}.[27]

Pritchett *et al*. compared the post-exercise consumption of chocolate milk (CHOC) to an over-the-counter recovery beverage (CRB) matched for CHO:PRO content and found creatine kinase (CK) was significantly (p<0.05) greater in the CRB trial compared with the CHOC trial (increase CHOC 27.9±134.8 $U.l^{-1}$, CRB 211.9±192.5$U.l^{-1}$); with differences not significant for CK post (CHOC 394.8 ±166.1 $U.l^{-1}$, CRB 489.1±264.4 $U.l^{-1}$) between the two trials.[27] Furthermore, a recent study found similar improvements in endurance performance between a CHO:PRO and a CHO-only beverage when matched for total kilocalories. Also, lower plasma CK levels were observed in the CHO:PRO v. CHO-only trial.[21]

The majority of studies only examined a single-dose recovery beverage ingested post exercise on muscle damage and performance but did not examine chronic training effects. The potential benefits of the recovery aid may be insignificant if not given adequate time to be effective, especially in highly trained athletes. More recent studies have examined a post-exercise nutritional beverage taken over time (6 days) on muscle damage. Luden *et al*. found significantly (p<0.05) lower CK levels with a CHO:PRO:A beverage (223.21±160.7 $U.l^{-1}$) versus the CHO- only beverage (307.3±312.9 $U.l^{-1}$). Muscle soreness, using a visual analog scale, was also reported to be significantly (p<0.05) lower after 5 days of post-exercise supplementation with the CHO:PRO:A beverage (1.0 VAS) v. the CHO only beverage (2.0 VAS). However, the effect of protein on protein synthesis and protein degradation in this study cannot be ruled out. It is not evident whether the results of this study were due to supplementation during exercise, after exercise, or in combination. The authors offered that it cannot be ruled out that the attenuation in CK levels may be due to the additional calories, or improvements in protein synthesis with the CHO:PRO:A beverage.[26]

Similarly, Skillen *et al*. reported decreases in CK levels and fatigue following 90 minutes of cycling at 75% of VO_{2max} followed by a time trial to exhaustion at 85% of VO_{2max} after 2 weeks of supplementation in cyclists with a 3.6% CHO ±1% amino acid solution.[32] Gilson *et al*. examined the effectiveness of low-fat chocolate milk versus a high CHO recovery beverage consumed after exercise for a week in intercollegiate soccer players.[34] The soccer players continued their normal training regimen (which was similar among subjects). Similar to the findings of Luden *et al*.,[31] this study found significantly (p<0.05) lower CPK (CHOC: 316.9±188.3 $U.l^{-1}$, CHO:431.6±310.8 $U.l^{-1}$) levels after one week of supplementation with a beverage containing protein (chocolate milk) v. a high CHO-only beverage. However, no differences in performance were reported between beverages.[34]

In conclusion, post-exercise recovery beverages containing protein seem to be effective in improving recovery indices. However, some of the results may be due to the higher caloric content of the CHO:PRO supplements. The additional protein calories via glucogenesis may have provided additional substrate for glycogen resynthesis to occur, therefore aiding in an enhanced recovery.[12] Currently research suggests that 20 - 25 g of high-quality protein during a single feeding is optimal. Future research should examine the type of protein, timing of intake, and the effects of distribution of protein throughout the day on recovery indices.[3]

Type of recovery meals

Research examining the effects of a post-exercise feeding has exclusively supplemented with a beverage or solid rather than a gel feeding. One reason for this may be that gels are typically consumed during endurance exercise. It appears that the same benefits would be observed with a meal that is in the form of a solid or liquid feeding.[3] Consequently, current recommendations are based on research that has examined recovery meals in liquid or solid form.

To our knowledge, one study has examined the effects of a post-exercise CHO-only oral gel versus a CHO:PRO oral gel on endurance performance and muscle damage. Saunders *et al*. compared the effectiveness of a CHO:PRO gel to a CHO-only gel consumed during and after exercise on muscle damage and performance measures. In a cycling time trial to volitional exhaustion at 75% of VO_2 peak, subjects cycled 13% longer ($p<0.05$) with the CHO:PRO gel compared with the CHO-only gel. Also, CK levels significantly increased ($p<0.05$) after exercise with the CHO-only gel compared with the CHO:PRO gel.[25]

Limitations of studies

Various limitations have been discussed throughout the studies that have examined post-exercise nutritional strategies for optimal recovery. The vast majority of the studies examined the acute effects of post-exercise recovery on exercise performance. Practically it would be more beneficial to examine the effects of these nutritional strategies over a longer duration similar to a training regimen.

Extraneous variables such as dietary intake and sleep patterns were often not controlled in the studies. In order to examine the effect of a recovery beverage on performance and recovery, it is vital to control for dietary intake. It is ideal to provide a food frequency questionnaire as well as a 3-day food record to get an accurate depiction of diet. Sleep is another variable that could influence the results of study, therefore variations in sleep patterns should be considered when comparing trials.

Over the past 5 years, evidence has suggested a CHO:PRO beverage may be more beneficial in enhancing endurance performances compared with a CHO-only beverage.[35] A major concern that has been addressed in a number of the studies is the inconsistency of the calories between treatments (i.e. CHO v. CHO:PRO beverages). Providing isocaloric beverages would be beneficial in determining whether it is the addition of protein, or the additional calories, that are responsible for the results.

Research on post-exercise nutritional strategies has primarily been done on males. A study by Tarnopolsky *et al*. suggested males oxidise higher proportion of carbohydrate during exercise than females.[36] Therefore, recommendations that have been established may only be effective for males and should be examined in females.

Future research

Future research should examine isocaloric beverages when comparing beverages of different compositions on recovery. Because it is ideal to incorporate a recovery beverage into athletes' daily regimens, it would be more beneficial to the athletic population to examine the effectiveness of a post-exercise recovery beverage taken on a daily basis.

Future research should examine other measures of muscle damage. Creatine phosphokinase and subjective measures of muscle soreness have been the primary dependent variables in the literature. Due to the variable nature of CK, measuring other blood parameters such as LDH, myoglobin and cortisol in conjunction with CK would enhance the quality of the studies.

It has also been noted that frequent post-exercise feedings may be beneficial in enhancing glycogen resynthesis. Perhaps providing glucose at a metered rate rather than as a bolus would provide higher plasma glucose and insulin levels, resulting in enhanced glycogen resynthesis.[1] Therefore research should examine differences in a metered post-exercise feeding v. a large bolus feeding.

Many athletes, particularly cyclists, consume foods in solid or gel forms during workout or competition. For practical purposes, research should examine differences in solid, liquid and gel forms of recovery meals on muscle glycogen resynthesis, and other recovery measures.

Practical applications

The literature that is available regarding post-exercise nutritional strategies for optimal performance is evolving. We suggest that the optimal timing regarding post-exercise nutritional strategies for maximal glycogen resynthesis is within the first 2 hours after exercise.[6,15-17] Also, the literature suggests that 1.0 - 1.5 $g.kg^{-1}.h^{-1}$ may be optimal for recovery.[1,11,15] The addition of 20 - 25 g of high-quality protein to a recovery meal may aid in muscle protein resynthesis.[3, 6,15-17]

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