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Effect of Carbohydrate-Protein (CHO-P) Supplement on Attenuation of Muscle Damage Induced by Eccentric Exercise in Turkish Ski Racers

Türk Yarışmacı Kayakçılarda Egzantrik Kasılmalara Bağlı Kas Hasarına Karbonhidrat-Protein (CHO-P) Suplementinin Etkisi

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Summary

Objective: It has been reported that eccentric muscle contractions induce muscle damage more than other types of exercise. The purpose of the present study was to investigate the effect of carbohydrate-protein (CHO-P) supplement on attenuation of muscle damage during skiing, which mostly includes eccentric muscle contractions.

Materials and Methods: Creatine kinase (CK) activity was measured as an indicator of muscle damage in skiers using placebo or CHO-P. The exercise was composed of skiing on a track of 510 m repeated 6 times. The CHO-P group consumed a total 108 g CHO and 24 g protein with 1500 ml of fluid. The placebo group consumed a beverage similar in taste and electrolyte concentration to CHO-P but not containing carbohydrate and/or protein. Venous blood samples were collected immediately before skiing and 5 minutes, one hour and 4 hours after the final run.

Results: This study demonstrated that ingestion of CHO-P fluid supplementation minimizes exercise-induced increase in CK 4 h after alpine skiing ($p<0.05$).

Conclusion: Ingestion of CHO-P as fluid supplement in physical activities performed in a cold environment for a long time, such as skiing that involves predominantly eccentric muscle action, is able to minimize exercise-induced muscle damage. This practice provides faster recovery for athletes during subsequent trainings. *Turk J Phys Med Rehab 2011;57:14-8.*

Key Words: Carbohydrate–protein (CHO-P) supplement, muscle damage, skiers

Özet

Amaç: Egzantrik kas kasılmalarının diğer kasılma türlerinden daha fazla kas hasarına neden olduğu bildirilmiştir. Bu çalışmanın amacı büyük oranda egzantrik kasılmalardan oluşan kayak aktivitesi süresince karbonhidrat-protein (CHO-P) içeren bir suplement alınmasının kas hasarı üzerine etkisini araştırmaktır.

Gereç ve Yöntem: Kas hasarının bir belirleyicisi olarak kreatin kinaz (CK) düzeyleri plasebo ve CHO-P gruplarında ölçüldü. Egzersiz 510 m uzunluğundaki bir pist üzerinde 6 tekrar yapılarak tamamlandı. CHO-P grup 1500 ml sıvı ile birlikte toplam 108 gr karbonhidrat ve 24 gr protein tüketti. Plasebo grup benzer tad ve elektrolit konsantrasyonuna sahip karbonhidrat ve protein içermeyen aynı miktarda sıvı tükettiler. Egzersizden önce, 5 dakika 1 saat ve 4 saat sonra venöz kan örnekleri alındı.

Bulgular: Kayak egzersizi süresince alınan CHO-P suplementi egzersizden 4 saat sonra CK artışını plasebo grubuna göre anlamlı derecede düşürdü ($p<0,05$).

Sonuç: Kayak gibi büyük oranda egzantrik kas kasılması gerektiren ve uzun süre soğuk bir ortamda yapılan fiziksel aktiviteler süresince CHO-P içeren bir sıvı suplementin alınması kas hasarını azaltarak, sonraki aktivite için sporcunun daha kısa sürede hazır hale gelmesine katkı sağlayabilir. *Türk Fiz Tıp Rehab Derg 2011;57:14-8.*

Anahtar Kelimeler: Karbonhidrat-protein suplement (CHO-P), kas hasarı, kayakçılar

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Introduction

During intensive exercise, strong mechanical forces applied to skeletal muscles can induce muscle damage which leads to an acute inflammatory response, pain, and a decrease in muscle force-generating capacity (1). Exercise-induced muscle damage occurs after either unaccustomed or intense and prolonged physical activity, and is characterized by increased muscle soreness and swelling, Z-line streaming, general myofilament disorganization, decreased maximal voluntary isometric force production, and an increase in intramuscular proteins in blood (2-6).

Muscle damage is induced by eccentric rather than concentric contractions (7). Eccentric muscle contractions are actions in which a muscle exerts a force while lengthening. A strenuous unaccustomed bout of this exercise type causes temporary ultra- structural muscle damage. Such actions are used to resist external forces like gravity (8,9). Berg and Eiken (10) have noted that eccentric muscle contractions are the primary muscle contraction employed during skiing. These authors have also reported that in all disciplines of skiing, electromyography (EMG) activity reaches near-maximum levels during the course of a turn. Another study has reported that EMG amplitudes ranged from 40 to 150% of maximum isometric voluntary contractions during long-radius giant slalom turns (11).

Because muscle glycogen is an essential fuel source for moderate-to-high-intensity exercise, a great quantity of the muscle glycogen stores is depleted during activities lasting longer than one hour, such as skiing. This results in a severe decrease in the muscle capacity which is necessary to perform these intense exercises (12). Therefore, the faster the muscle glycogen stores can be replenished after exercise, the faster will be the recovery process and theoretically the greater the return of performance capacity (13). Likewise, several researchers have found that the combination of carbohydrate and protein was more effective than carbohydrate alone in the replenishment of muscle glycogen during the first 4 h after exercise and that post-exercise muscle glycogen storage can be enhanced by a carbohydrate-protein (CHO-P) supplement as a result of the interaction of carbohydrate and protein on insulin secretion (14,15). In the same way, Cockburn et al. (16) have announced that 48 hours after exercise, milk and milk-based CHO-P supplementation attenuated the decreases in isokinetic muscle performance and increases in creatine kinase (CK) due to exercise-induced muscle damage.

The purpose of this study was to examine the effect of CHO-P supplementation during exercise on plasma CK levels, an important indicator of muscle damage after ski exercise.

Materials and Methods

Participants

Sixteen healthy male skiers, who were at intermediate level, voluntarily participated in the study. The study was approved by the Local Ethics Committee. Participants read and signed an informed consent form for the protection of human subjects according to the Declaration of Helsinki. Using random number tables, the participants were randomly divided into two groups to receive either placebo or CHO-P. Randomization was performed by an external scientist. Table 1 summarizes the general characteristics of the participants.

Experimental Protocol

The participants did not take part in any physical activity programs three days prior to this study. Before each of the six runs, the subjects ingested 250 ml of (1500 ml in total) CHO-P drink containing 18 g carbohydrate, 4 g protein, 170 mg sodium and 65 mg potassium or an equal volume of placebo similar in taste and electrolyte concentration to CHO-P but not containing carbohydrate and protein.

Exercise Protocol

Skiers ran a 510 m long track that involved 30 gates, 6 times consecutively. It took skiers about 9 minutes to reach again the starting point by the ski lift after each run. All skiers were instructed to ski at self-selected paces and to avoid stopping during the run. During the study, the average temperature was -15ºC.

Laboratory Analyses

Venous blood samples were collected immediately before skiing and 5 minutes, one hour and 4 hours after the final run.

All samples were allowed to clot at room temperature for 30 min and centrifuged for 10 min at 1500 g. The serum was removed and kept frozen as multiple aliquots at -20ºC until use. Serum CK activity was determined by spectrophotometer (Olympus 2700 Autoanalyzer, Japan) using a commercially available kit (Megalab, Athens, Greece). The measurement of lactic acid (LA) in whole blood was done using enzymatic-amperometric biosensor methods (NOVA biomedical CCX, Waltham, MA, USA). The normal reference range of CK activity for men using this method is 45–130 IU/L.

Statistical Analyses

Statistical analyses were performed using the statistical package SPSS version 12.0 (SPSS, Chicago, IL, USA). Data with a non-normal distribution were normalized using a logarithmic transformation prior to analysis. Difference between dependent groups was determined using the Wilcoxon signed-rank test, whereas that between independent groups was measured by the Mann-Whitney U test. The level of statistical significance p was taken as <0.05.

Power and sample size calculations were based on the main outcome-CK. Taking the standard deviation as 13 IU/L, alpha as 0.05, and effect of interest as 20 IU/L, 8 participants in each group gives a power of 81.6% for performing the independent-samples t test.

Table 1. Demographic characteristics of CHO-P and placebo groups (mean±standart deviation).

Group	Placebo (n=8)	CHO-P (n=8)	p
Age (years)	22±1.46	21.73±1.28	NS
Height (cm)	175±5.03	177±3.82	NS
Body weight (kg)	74.57±4.41	73.83±3.13	NS
NS: not significant			

Results

Characteristics of participants are present in Table 1. There were no differences in age, height, and body weight between the groups.

Comparisons of CK levels between groups are presented in Figure 1. Before exercise, the mean CK value in CHO-P group was 223.6±86.5 IU/L, while that in placebo group was 178.0±75.1 IU/L. The mean CK values in placebo and CHO-P groups were, respectively, 274.5±114.2 IU/L and 284.8±109.3 IU/L immediately after exercise, 348.6±124.3 IU/L and 314.4±113.4 IU/L 1 h after exercise, and 491.8±94.3 IU/L and 334.5±106.6 IU/L 4 h after exercise. There was a significant difference between the placebo and CHO-P groups only in the mean CK values 4 h after exercise.

To compare the increase in CK levels with exercise, changes from the baseline values were calculated. Although there was no significant difference in the baseline CK levels in both groups, increment in the CK levels were less in the CHO-P group and CK differences became significant right after exercise. Changes in CK levels in placebo and CHO-P groups were 96.5±40.1 vs. 61.2±25.2 ($p<0.05$), 170.6±70.0 vs. 90.8±38.4 ($p<0.05$), and 313.8±125.6 vs. 110.9±44.3 ($p<0.05$) right, 1 hour, and 4 hours after exercise, respectively.

Comparison between the mean LA levels in the placebo and CHO-P groups is presented in Figure 2. None of the differences were significant either for before, immediately after and 1h after exercise ($p>0.05$).

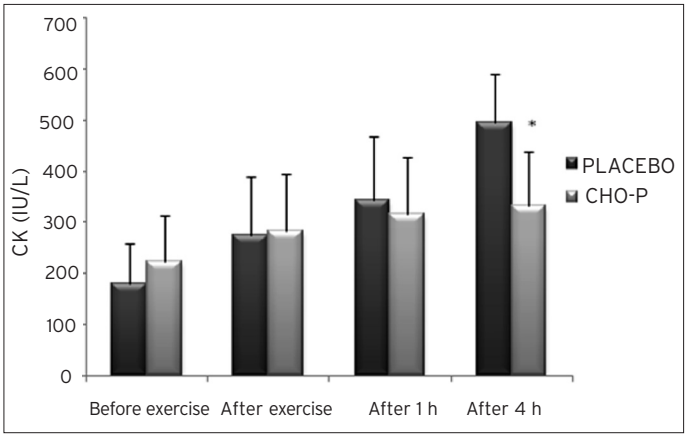

Figure 1. Comparison of CK levels between the groups.

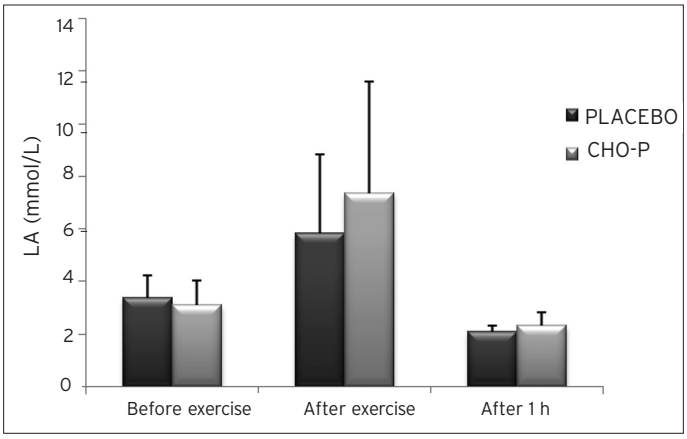

Figure 2. Comparison between LA levels in the groups.

Discussion

Serum CK levels in blood are used as an indicator of muscle damage (17-20). Armstrong (17) reported that increased cell membrane permeability led to increased efflux of CK from the cytosol. Under normal conditions, enzyme molecules pass through plasma membrane to a limited extent because of their big size. However, under certain circumstances, such as hypoxia and infectious diseases, if cell membrane is damaged, the selective permeability characteristics of the cell membrane are deteriorated. According to degree of damage, at first, the enzymes located on the surface of the cell membrane are mixed up into the plasma. Later, according to their cytosolic concentrations and molecular sizes, the intracellular enzymes leak into the plasma. If cell damage is very big and affects mitochondria, mitochondrial enzymes also appear in the plasma (17).

In the present study, the mean plasma CK level in CHO-P group decreased by 33% compared to the placebo group 4 h after skiing. According to the author's knowledge, there are few studies on the effect of energy supplements on the plasma CK levels in skiers in the literature. In the only study in recreational skiers, the mean CK level did not change from pre-skiing to 2 h post-skiing in CHO-P group, but increased significantly from 117±7.2 to 174±43.4 IU/L for placebo group and from 126±23.2 to 243±34.3 U/L for no fluid group (7). On the other hand, many articles are available on the beneficial effect of CHO-P supplement on attenuation of muscle damage as indicated by the increase in plasma CK in exercises other than skiing (4,21-28). Saunders et al. (21) have reported that 15 h after exhaustive cycle exercise, the mean plasma CK level in athletes given CHO-P supplement during exercise was 83% lower than those given CHO-only supplement. Ready et al. (22) have noted a similar result (but a 38% decrease) in mean plasma CK levels in CHO-P supplemented athletes compared to CHO-only supplemented group 24 h after 45-min jogging plus 90-min cycle exercise.

Skiing is excessively affected by environmental factors. In cold weather, the exercising body has to face numerous metabolic, thermoregulatory and cardiovascular changes. Because cold exposure increases the glycolytic rate, it also increases glycogenolysis (23,24). In a cold environment, 60% of body temperature is provided by carbohydrates. The sources of the carbohydrates for heat production are muscle glycogen and plasma glucose. The oxidation of muscle glycogen doubles during mild cold exposure, providing 75% of total CHO oxidized. This process is responsible for 40% of total heat production (24). In skiing, intense muscle contractions might be required throughout a turn followed by a relatively relaxed period. These repeated stimuli will tax the glycolytic energy system and, consequently, affect muscle glycogen stores (25,26).

Cold environment and physiological forces can cause ischemia and hypoxia. Ischemia might negatively influence muscle metabolism by increasing glycogen utilization or by reducing glucose uptake by the muscle (27-29). During alpine skiing, maintaining substrate availability to the active muscles could be crucial in minimizing muscle damage, since muscle glycogen is used at high rates and glucose uptake is reduced. Tesch et al. (26) have notified that skiers experienced muscle glycogen depletion by more than 50%

with 20% of muscle fibers being void of glycogen. Ingesting an energy supplement during skiing would provide the substrate for an immediate need of energy as well as aid recovery by facilitating glycogen replenishment between runs. A series of studies have shown that adding a small amount of protein to a carbohydrate drink is more beneficial to muscle glycogen synthesis than a drink containing only carbohydrate (21,22,30-36). Ivy et al. (30) observed that in the athletes who ingested a CHO-P drink, 22% of muscle glycogen restored in 40 minutes following an exhaustive exercise bout and the restoration rate of glycogen was four times faster compared to CHO-only supplemented athletes. In another study, Zawadzki et al. (14) have reported that during 4 h after exercise, there was a 38% increase in muscle glycogen when 0.6 g protein was added to 1.6 g carbohydrate per kg.

Several studies have declared that the cause of alterations in muscle glycogen stores after CHO supplementation is, in part, based on changes in plasma insulin levels and adding protein to CHO solution can increase the insulin activity more than a CHO-only supplement (14,37,38). Insulin acts both by increasing the rate of protein synthesis and decreasing the rate of protein breakdown to reduce muscle damage following resistance exercise (39-41). In subjects who were infused with several trace amino acids prior to exercise, the insulin infusion following a bout of resistance exercises for 3 hours significantly reduced protein breakdown (41). Gelfand et al. (42) infused insulin for 2 hours in resting subjects and found a significant reduction in the rate of protein breakdown. Thus, insulin infusion can limit the CK efflux out of the muscle into the plasma (43,44).

The combined effects of carbohydrate and amino acids are more potent than when they are ingested separately. Miller et al. (32) reported that increased synthesis rates in people fed with amino acids only was not as robust as when supplementing with a mixture of carbohydrate and essential amino acids. Levenhagen et al. (45) provided subjects with placebo, a CHO supplement, or a CHO-PRO supplement. The rates of leg muscle protein synthesis following CHO-PRO supplementation improved 600% compared with placebo and 400% compared with CHO-only supplementation (45).

In this study, blood LA levels in both groups significantly increased after exercise. Although the difference between the groups was not significant, LA increase was excessive in the CHO-P group than in the placebo group, immediately after exercise. Likely, cause of this might be that increasing substrate availability stimulates glycolysis, and accordingly, LA concentration increases. De Sausa et al. (46) reported that the mean blood lactate was significantly higher in the CHO (11.4±4.9 mmol L^{-1}) than in the placebo group (8.4±5.1 mmol L^{-1}) at the end of the protocol ($p<0.05$) and that blood lactate concentrations decreased during the recovery period, returning to the pre-exercise values. Haff et al. (47) determined that LA levels increased in both exercise group given CHO supplement and placebo group before and after isometric exercise.

In summary, the findings of this study demonstrated that during alpine skiing, CHO-P supplementation minimized the increase in plasma CK, an important indicator of muscle damage, compared to the placebo group. During physical activities involving predominantly eccentric muscle contractions and performed in a cold environment for a long time ingestion of CHO-P as a fluid supplement is able to minimize exercise-induced muscle damage. This application can be useful in recovering from muscle damage caused by eccentric exercise and helps athletes to maintain their performance for subsequent trainings.

References

1. Buckley JD, Thomson RL, Coates AM, Howe, PRC, DeNichilo MO, Rowney MK. Supplementation with a whey protein hydrolysate enhances recovery of muscle force-generating capacity following eccentric exercise. J Sci Med Sport 2008;13:178-81. [Abstract] / [Full Text] / [PDF]
2. Clarkson PM, Hubal MJ. Exercise-induced muscle damage in humans. Am J Phys Med Rehabil 2002;81:52-69. [Abstract]
3. Tee JC, Bosch AN, Lambert MI. Metabolic consequences of exercise-induced muscle damage. Sports Med 2007;37:827-36. [Abstract]
4. Greer, BK, Woodard, JL, White JP, Arguello EM, Haymes EM. Branched-Chain amino acid supplementation and indicators of muscle damage after endurance exercise. Int J Sport Nutr and Exerc Metab 2007;17:595-607. [Abstract]
5. Philippou A, Bogdanis GC, Maridaki M. Isotonic muscle function is selectively reduced after muscle damage induced by isometric exercise at a long muscle length. Isokinet Exerc Sci 2007;15:69-75. [Abstract] / [Full Text] / [PDF]
6. Howatson G, van Someren KA. The prevention and treatment of exercise- induced muscle damage. Sports Med 2008;38:483-503. [Abstract]
7. Seifert, JG, Kipp RW, Amann M, Gazal O. Muscle damage, fluid ingestion, and energy suppplementation during recreational alpine skiing. Int J Sport Nutr Exerc Metab 2005;15:528-36. [Abstract]
8. Stauber WT. Eccentric action of muscles: physiology, injury, and adaptation. Exerc Sport Sci Rev 1989;17:157-85. [Abstract]
9. Asp S, Daugaard JR, Kristiansen S, Kiens B, Richte EA. Exercise metabolism in human skeletal muscle exposed to prior eccentric exercise. J Physiol 1998;509:305-13. [Abstract] / [Full Text] / [PDF]
10. Berg HE, Eiken O. Muscle control in elite alpine skiing. Med Sci Sports Exerc 1999;31:1065-7. [Abstract]
11. Hintermeister RA, O'Connor DD, Lange GW, Dillman CJ, Steadman JR. Muscle activity in wedge, parallel, and giant slalom skiing. Med Sci Sports Exerc 1997;29:548-53. [Abstract]
12. Coyle EF, Coggan AR, Hemmert MK, Ivy JL. Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. J Appl Physiol 1986;61:165-72. [Abstract] / [PDF]
13. Levenhagen DK, Gresham JD, Carlson MG, Maron DJ, Borel MJ, Flakoll PJ. Postexercise nutrient intake timing in humans is critical to recovery of leg glucose and protein homeostasis. Am J Physiol Endocrinol Metab 2001;280:982-93. [Abstract] / [Full Text] / [PDF]
14. Zawadzki KM, Yaspelkis BB, Ivy JL. Carbohydrate-protein complex increases the rate of muscle glycogen storage after exercise. J Applied Physiol 1992;72:1854-9. [Abstract] / [PDF]
15. Saunders MJ. Coingestion of carbohydrate-protein during endurance exercise influence on performance and recovery. Int J Sport Nutr Exerc Metab 2007;17:87-103.
16. Cockburn E, Hayes PR, French DN, Stevenson E, St Clair Gibson A. Acute milk-based protein-CHO supplementation attenuates exercise-induced muscle damage. Appl Physiol Nutr Metab 2008;33:775-83. [Abstract] / [Full Text] / [PDF]
17. Armstrong RB. Mechanisms of exercise-induced delayed onset muscular soreness: a brief review. Med Sci Sports Exerc 1984;16:529-38. [Abstract]
18. Clarkson PM, Byrnes WC, McCormick KM, Turcotte LP, White JS. Muscle soreness and serum creatine kinase activity following isometric, eccentric, and concentric exercise. Int J Sports Med 1986;7:152-5. [Full Text] / [PDF]
19. Newham DJ, Jones DA, Edwards RH. Large delayed plasma creatine kinase changes after stepping exercise. Muscle Nerve 1983;6:380-5. [Abstract]

20. Newham DJ, Jones DA, Clarkson PM. Repeated high-force eccentric exercise: effects on muscle pain and damage. J Appl Physiol 1987;63:1381-6. [Abstract] / [PDF]
21. Saunders MJ, Kane MD, Todd MK. Effects of a carbohydrate-protein beverage on cycling endurance and muscle damage. Med Sci Sports Exerc 2004;36:1233-8. [Abstract]
22. Ready S, JG Seifert, ER Burke. The effects of two sports drink formulations on muscle stress and performance. Med Sci Sport Exerc 1999;31:119. [Abstract]
23. Haman F, Peronnet F, Kenny GP, Massicotte D, Lavoie C, Scott C, et al. Effect of cold exposure on fuel utilization in humans: plasma glucose, muscle glycogen, and lipids. J Appl Physiol 2002;93:77-84. [Abstract] / [Full Text] / [PDF]
24. Jacobs I, Romet TT, Kerrigan-Brown D. Muscle glycogen depletion during exercise at 9 degrees C and 21 degrees C. Eur J Appl Physiol Occup Physiol 1985;54:35-9. [Abstract]
25. Tesch PA. Aspects on muscle properties and use in competitive Alpine skiing. Med Sci Sports Exerc 1995;27:310-4. [Abstract]
26. Tesch PA, Larson L, Eriksson A, Karlsson J. Muscle glycogen depletion and lactate concentration during downhill skiing. Med Sci Sports 1978;10:85-90. [Abstract]
27. Kemp GJ, Roussel M, Bendahan D, Le Fur Y, Cozzone PJ. Interrelations of ATP synthesis and proton handling in ischaemically exercising human forearm muscle studied by 31P magnetic resonance spectroscopy. J Physiol 2001;15:901-28. [Abstract] / [Full Text] / [PDF]
28. Parolin ML, Spriet LL, Hultman E, Matsos MP, Hollidge-Horvat MG, Jones NL, et al. Effects of PDH activation by dichloroacetate in human skeletal muscle during exercise in hypoxia. Am J Physiol Endocrinol Metab 2000;279:752-61. [Abstract] / [Full Text] / [PDF]
29. Roy BD, Gren HJ, Burnett M. Prolonged exercise after diuretic-induced hypohydration: effects on substrate turnover and oxidation. Am J Physiol Endocrinol Metab 2000;279:1383-90. [Abstract] / [Full Text] / [PDF]
30. Ivy JL, Goforth HW, Damon BM, McCauley TR, Parsons EC, Price TB. Early postexercise muscle glycogen recovery is enhanced with a carbohydrate-protein supplement. J Appl Physiol 2002;93:1337-44. [Abstract] / [Full Text] / [PDF]
31. Williams MB, Raven PB, Fogt DL, Ivy JL. Effects of recovery beverages on glycogen restoration and endurance exercise performance. J Strength Cond Res 2003;17:12-9. [Abstract]
32. Miller SL, Tipton KD, Chinkes DL, Wolf SE, Wolfe RR. Independent and combined effects of amino acids and glucose after resistance exercise. Med Sci Sports Exerc 2003;35:449-55. [Abstract]
33. Saunders MJ, Luden ND, Herrick JE. Consumption of an oral carbohydrate-protein gel improves cycling endurance and prevents postexercise muscle damage. J Strength Cond Res 2007;21:678-84. [Abstract]
34. Valentine RJ, Saunders MJ, Todd MK, St Laurent TG. Influence of carbohydrate-protein beverage on cycling endurance and indices of muscle disruption. Int Sport Nutr Exerc Metab 2008;18:363-78. [Abstract]
35. Saunders MJ, Moore RW, Kies AK, Luden ND, Pratt CA. Carbohydrate and protein hydrolysate coingestions improvement of late-exercise time-trial performance. Int J Sport Nutr Exerc Metab 2009;19:136-49. [Abstract]
36. Skillen RA, Testa M, Applegate EA, Heiden EA, Fascetti AJ, Casazza GA. Effects of an amino acid carbohydrate drink on exercise performance after consecutive-day exercise bouts. Int Sport Nutr Exerc Metab 2008;18:473-92. [Abstract]
37. Reed MJ, Brozinick JT Jr, Lee MC, Ivy JL. Muscle glycogen storage postexercise: effect of mode of carbohydrate administration. J Appl Physiol 1989;66:720-6. [Abstract] / [PDF]
38. Ivy JL, Katz AL, Cutler CL, Sherman WM, Coyle EF. Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion. J Appl Physiol 1988;64:1480-5. [Abstract] / [PDF]
39. Biolo G, Declan Fleming RY, Wolfe RR. Physiologic hyperinsulinemia stimulates protein synthesis and enhances transport of selected amino acids in human skeletal muscle. J Clin Invest 1995;95:811-9. [Abstract] / [PDF]
40. Biolo G, Williams BD, Fleming RY, Wolfe RR. Insulin action on muscle protein kinetics and amino acid transport during recovery after resistance exercise. Diabetes 1999;48:949-57. [Abstract] / [PDF]
41. Roy BD, Tarnopolsky MA, MacDougall JD, Fowles J, Yarasheski KE. Effect of glucose supplement timing on protein metabolism after resistance training. J Appl Physiol 1997;82:1882-8. [Abstract] / [Full Text] / [PDF]
42. Gelfand RA, Barrett EJ. Effect of physiologic hyperinsulinemia on skeletal muscle protein synthesis and breakdown in man. Clin Invest 1987;80:1-6. [Abstract] / [PDF]
43. Bloomer RJ, Goldfarb AH. Can nutritional supplements reduce exercise-induced skeletal damage? Strength Cond 2003;25:30-7. [Abstract]
44. Baty JJ, Hwang H, Ding Z, Bernard JR, Wang B, Kwon B, et al. The effect of a carbohydrate and protein supplement on resistance exercise performance, hormonal response, and muscle damage. J Strength Cond Res 2007;21:321-9. [Abstract]
45. Levenhagen DK, Carr C, Carlson MG, Maron DJ, Borel MJ, Flakoll PJ. Postexercise protein intake enhances whole-body and leg protein accretion in humans. Med Sci Sports Exerc 2002;34:828-37. [Abstract]
46. De Sousa MV, Simoes HG, Oshiiwa M. Effects of acute carbohydrate supplemation during sessions of high-intensity intermittent exercise. Eur J Appl Physiol 2007;99:57-63. [Abstract] / [PDF]
47. Haff GG, Koch AJ, Potteiger JA, Kuphal KE, Magee LM, Green SB, et al. Carbohydrate supplementation attenuatesmuscle glycogen loss during acute bouts of resistance exercise. Int J Sport Nutr Exerc Metab 2000;10:326-39. [Abstract]