RESISTANCE TRAINING & BETA-HYDROXY-BETA-METHYLBUTYRATE SUPPLEMENTATION ON HORMONES

Original Article
Artigo Original
Artículo Original

TREINAMENTO DE RESISTÊNCIA E SUPLEMENTAÇÃO DE BETA-HIDROXI-BETA-METILBUTIRATO EM HORMÔNIOS

ENTRENAMIENTO DE RESISTENCIA Y SUPLEMENTACIÓN DE BETA-HIDROXI-BETA-METILBUTIRATO EN HORMONAS

Hamid Arazi[1]
(Exercise Physiologist)
Hadi Rohani[2]
(Exercise Physiologist)
Ahmad Ghiasi[1]
(Exercise Physiologist)
Nasrin Abdi Keikanloo[3]
(Exercise Physiologist)

1. University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, Rasht, Iran.
2. Sport Sciences Research Institute, Tehran, Iran.
3. Payame Noor University, Tehran Branch, Tehran, Iran.

Correspondence:
University of Guilan, Faculty of Sport Sciences, Department of Exercise Physiology, P.O. Box 41635-1438, Rasht, Iran.
hamidarazi@yahoo.com

RESUMO

Introduction: In recent years, there was an increased interest on the effects of beta-hydroxy-beta-methylbutyrate (HMB) supplementation on skeletal muscle due to its anti-catabolic effects. Objectives: To investigate the effect of HMB supplementation on body composition, muscular strength and anabolic-catabolic hormones after resistance training. Methods: Twenty amateur male athletes were randomly assigned to supplement and control groups in a double-blind crossover design and participated in four weeks resistance training. Before and after the test period fasting blood samples were obtained to determine anabolic (the growth hormone and testosterone) and catabolic (cortisol) hormones, and fat mass, lean body mass (LBM) and muscular strength were measured. Dependent and independent t-tests were used to analyze data. Results: After the training period, there were no significant differences between the groups with respect to fat mass, LBM and anabolic-catabolic hormones. HMB supplementation resulted in a significantly greater strength gain ($p \leq 0.05$). Conclusion: Greater increase in strength for HMB group was not accompanied by body composition and basal circulating anabolic-catabolic hormonal changes. It seems that HMB supplementation may have beneficial effects on neurological adaptations of strength gain.

Keywords: resistance training, hormones, body composition, dietary supplements, HMB, muscle strength.

ABSTRACT

Introduçao: Nos últimos anos, houve um aumento no interesse sobre os efeitos da suplementação de beta-hidroxi--beta-metilbutirato (HMB) no musculoesquelético devido aos seus efeitos anticatabólicos. Objetivos: Investigar o efeito da suplementação de HMB na composição corporal, força muscular e hormônios anabólicos-catabólicos após treinamento de resistência. Métodos: Vinte atletas amadores do sexo masculino foram aleatoriamente designados a grupos de suplemento e de controle em design cruzado duplo-cego, tendo participado de treinamento de resistência durante quatro semanas. Antes e depois do período de teste, foram obtidas amostras de sangue em jejum para determinar os hormônios anabólicos (o hormônio do crescimento e a testosterona) e catabólico (cortisol), tendo a massa adiposa, massa corporal magra (LBM) e força muscular sido mensuradas. Testes t dependentes e independentes foram usados para analisar os dados. Resultados: Após o período de treinamento, não houve nenhuma diferença significativa entre os grupos no que diz respeito à massa adiposa, LBM e hormônios anabólicos-catabólicos. A suplementação de HMB resultou em um ganho de força significativamente maior ($p<0,05$). Conclusão: O maior aumento na força no grupo HMB não foi acompanhado por alterações na composição corporal e alterações hormonais anabólicas-catabólicas basais na circulação. Parece que a suplementação de HMB pode ter efeitos benéficos sobre as adaptações neurológicas do ganho de força.

Palavras-chave: *treinamento de resistência, hormônios, composição corporal, suplementos alimentares, HMB, força muscular.*

RESUMEN

Introducción: En los últimos años hubo un aumento en el interés sobre los efectos de la suplementación de beta-hidroxi-beta-metilbutirato (HMB) en el músculo esquelético debido a sus efectos anticatabólicos. Objetivos: Investigar el efecto de la suplementación de HMB en la composición corporal, fuerza muscular y hormonas anabólicas-catabólicas después de entrenamiento de resistencia. Métodos: Veinte atletas amateurs del sexo masculino fueron aleatoriamente designados a grupos de suplemento y de control en un diseño cruzado doble ciego, habiendo participado en entrenamiento de resistencia durante cuatro semanas. Antes y después del período de test, fueron obtenidas muestras de sangre en ayunas para determinar las hormonas anabólicas (la hormona del crecimiento y la testosterona) y catabólica (cortisol), habiendo sido medidas la masa adiposa, masa corporal magra (LBM) y fuerza muscular. Los Tests-t dependientes e independientes fueron usados para analizar los datos. Resultados: Después del período de entrenamiento, no hubo ninguna diferencia significativa entre los grupos en lo que se refiere a la masa adiposa, LBM y hormonas anabólicas-catabólicas. La suplementación de HMB resultó en un aumento de fuerza significativamente mayor ($p<0,05$). Conclusión: El mayor aumento en la fuerza en el grupo HMB no fue *acompañado por alteraciones en la composición corporal y alteraciones hormonales anabólicas-catabólicas basales en la circulación. Parece que la suplementación de HMB puede tener efectos benéficos sobre las adaptaciones neurológicas del aumento de fuerza.*

Palabras clave: *entrenamiento de resistencia, hormonas, composición corporal, suplementos alimentarios, HMB, fuerza muscular.*

DOI: http://dx.doi.org/10.1590/1517-869220152105113281 Artigo recebido em 12/03/2014 aprovado em 23/07/2015.

INTRODUCTION

Nutritional supplements are commonly used by athletes to enhance athletic performance. While it is believed that these substances increase the training-associated anabolic adaptations and reduce their catabolic effects, increase muscle mass and decrease fatigue, very little scientific evidence supports this notion. In recent years, there was an increase interest on the effects of beta-hydroxy beta-methylbutyrate (HMB) supplementation on skeletal muscle due to its anti-catabolic effects[1-3]. Studies examining the effects of HMB supplementation on strength and body composition have demonstrated that HMB supplementation, in combination with a resistance training program, resulted in increased muscular strength and lean body mass (LBM) and tended to decrease fat mass[4,5]. It has been suggested that HMB supplementation with 1.5 to 3 g per day reduces muscle proteolysis and increases strength and muscle mass after 3-8 weeks strength training[6,7]. However, these findings aren't confirmed by other studies[8,9].

HMB is a bioactive metabolite formed from the breakdown of the essential branched amino acid leucine. Leucine and its metabolite keto--isocaproate (KIC) appear to inhibit protein degradation and this anti-proteolytic effect is believed to be mediated by HMB. HMB exerts its effects through protective anti-catabolic mechanisms and has been shown to directly influence protein synthesis[10,11]. In fact, HMB supplementation may affect cellular receptors and hormones, such as cortisol and testosterone, or the modulation of enzymes responsible for muscle catabolism[10]. However, recent studies have generated a more concrete basis regarding HMB mechanisms of action[12]. Possible mechanisms of action include reduced muscle damage due to stabilization of muscle cell membrane, modulation of protein degradation by inhibition of the ubiquitin–proteosome system, and upregulation of IGF-1 gene expression in the skeletal muscle, and the mTOR signaling pathway leading to protein synthesis[13-15].

Although some findings suggest that HMB supplementation during training may enhances adaptations of trained and untrained individuals, others report no significant effects of HMB supplementation[8,16,17]. Thus, the available scientific literature on HMB supplementation in humans is still preliminary in nature and should be considered with reservation[11,18].Also, the data about the influence of HMB supplementation, particularly with resistance training, on anabolic-catabolic hormones are still scarce and to our knowledge there are only two studies with conflicting results[5,11] in the literature regarding the effect of HMB supplementation on these variables.

So, the aim of the present study was to assess the effect of HMB supplementation on body composition, muscular strength and, anabolic (the growth hormone and testosterone) and catabolic (cortisol) hormones after four weeks resistance training in amateur athletes. We hypothesized that HMB supplementation will lead to an increase in LBM, muscular strength and anabolic hormones, i.e. growth hormone and testosterone, and reduce fat mass and catabolic hormone, i.e. cortisol, after strength training.

MATERIALS AND METHODS

Twenty amateur athletes volunteered to participate in this study. None of the participants had a medical history of digestive and hormonal disorders, hypertension, liver dysfunction, cardiovascular disease and diabetes. They have no regular resistance training in past 6 months. Complete advice about possible risks and discomforts was given to the participants, and all of them give their written informed consent to participate. Their characteristics are shown in table 1.

Table 1. Characteristics of the participants (Mean ± SD).

Variables	Control	HMB
Age (years old)	22.7 ± 2.9	22.4 ± 3.4
Weight (kg)	73.3 ± 8.1	74. 8 ± 7.2
Height (cm)	175.7 ± 5.6	175.9 ± 5.1
BMI (kg/m^2)	23.6 ± 1.5	24.1 ± 1.9
Body Fat (%)	15.7 ± 2.3	14.9 ± 3.7
LBM (kg)	61.7 ± 6.2	63.5 ± 5.6

BMI: body mass index, LBM: lean body mass.

PROCEDURES

All procedures were in accordance with the Declaration of Helsinki and the study was approved by the faculty ethics committee in the University of Guilan, Rasht, Iran.

Before initiating the training, the participants underwent an anamnesis, a clinical evaluation and weight, height, body mass index (BMI), body fat mass and LBM measurements. Then, all of them underwent familiarization session to familiar with the procedures of the study and participated in one repetition maximum (1RM) strength test. Participants were randomly assigned to supplement and control groups in a double-blind crossover study and took part in four weeks resistance training. Blood samples were collected to measure the serum growth hormone, testosterone and cortisol concentrations before and after the training period, same as body composition and muscular strength.

All measurements were performed at the same time of the day for all participants. None of the participants received any additional medications or food supplements other than HMB or placebo. They were asked to maintain their usual dietary and lifestyle habits and not to perform strenuous physical activity in the period of study.

Anthropometric measurements were done in light clothes before and after the training period. Height and weight were measured by an automatic height–weight scale, to the nearest 0.1 cm and 0.1 kg, respectively. BMI was calculated by dividing weight (kg) by the square of the height (m^2). To estimate the amount of subcutaneous fat in the body, skinfold thickness was measured (Lafayette Caliper, model 01128, USA) at three sites (Chest, Abdomen and Quadriceps) in the right of body. Each measurement was performed in triplicate and the average was taken for analysis. All the measurements were made with the subject in standing position and body fat percent were estimated in accordance with Jackson and Pollack[19]. LBM was determined by subtracting the fat mass from weight.

1RM was assessed prior and at the end of the second week of training in the squat, knee extension, knee flexion, leg press, bench press, lat pull-down, shoulder press, cable biceps curl and triceps push down exercises. At the end of the training period, participants underwent 1RM test in the squat and bench press too. Briefly, participants performed a warm-up consist of slow running, static stretching, and dynamic exercises. Two to three trials separated by 2–3 min of rest were used to determine individual 1RM for each resistance exercise. In these sessions, a weight that can be lifted maximally to fatigue after 2-10 repetitions has been used to calculate 1RM, according to the formula proposed by Brzycki[20].

HMB supplementation and exercise protocol

Participants were randomly assigned to supplement and control groups in a double-blind crossover manner and trained together for four weeks. The supplement group consumed HMB (GNC Pro Performance®, USA) supplement 3 g per day in three times (total 12 capsules) and control group consumed placebo (rice flour) in this period. Both treatments had same shape as identical capsules in size and appearance. Each HMB capsule contained 250 mg Calcium Hydroxymethyl Butyrate Monohydrate (Ca-HMB) and 200mg Mono-Potassium phosphate (KH_2PO_4). Previous studies in adults suggested that the use of this dose resulted in the greatest effects on muscle mass and muscle strength[21]. Also, when supplementing with HMB, current evidence suggests that 1 g of HMB should be consumed three times per day, for a total of 3 g of HMB daily[13].

Exercise training involved resistance training in 3 sessions per week. Participants performed two sets of nine exercises (squat, knee extension, knee flexion, leg press, bench press, lat pull-down, shoulder press, cable biceps curl and triceps push down) per session, so that carried 10 repetitions for each set with 80% 1RM in first 2 weeks and 8 repetitions for each set with 85% of new determined 1RM in 2 last weeks. 2 and 3 min rest interval were assigned between sets and exercises, respectively.

Blood sampling and analysis

Blood samples obtained 1 day before and 3 days after the test period for determining the growth hormone, testosterone and cortisol levels. 10 cc blood samples were taken in a seated position from antecubital vein after 12 h overnight fasting. The samples were centrifuged and the serum was frozen and stored at -80°C until analyzing the hormones. Serum growth hormone, testosterone and cortisol levels were determined by radioimmunoassay (RIA) method (Immunotech Kits, Czech Republic; Gamma Counter System, LKB model, Finland). All samples were analyzed in same assay for each hormone according to the manufacturer's instruments. Coefficients of variation (CV) for all the variables were less than 7%.

Statistical analysis

All data were expressed as mean ± SD and were analyzed using SPSS software (Ver. 16.0). Paired and unpaired t-tests were used respectively to examine the within and between groups differences of variables. The level of significance was set at p≤0.05.

RESULTS

No baseline differences were found between the HMB and control groups in anthropometric characteristics (table 1). Pre and post-training values of body weight, BMI, percent body fat and LBM of HMB and control groups are shown in table 2. Body weight (p=0.001, p=0.001), BMI (p=0.001, p=0.001) and LBM (p=0.001, p=0.001) increased and percent body fat (p=0.007, p=0.002) decreased significantly after training period in both HMB and control groups. However, there were no significant differences in these variables changes between the groups.

Table 2. Pre and post-training anthropometric measures.

Variables	Control			HMB		
	Pre	Post	Delta	Pre	Post	Delta
Weight (kg)	73.3 ± 8.1	74.7 ± 8.0*	1.4 ± 0.8	74.8 ± 7.2	76.6 ± 7.9*	1.8 ± 1.2
BMI (kg/m²)	23.6 ± 1.5	24.1 ± 1.6*	0.5 ± 0.3	24.1 ± 1.9	24.7 ± 2.3*	0.6 ± 0.4
Body fat (%)	15.7 ± 2.3	14.7 ± 2.5*	-0.9 ± 0.8	14.9 ± 3.7	13.4 ± 3.3*	-1.5 ± 1.1
LBM (kg)	61.7 ± 6.2	63.6 ± 6.5*	2.7 ± 1.4	63.5 ± 5.6	66.3 ± 6.5*	1.9 ± 1.2

Values are expressed as mean ± SD; Delta: post-pre values. BMI: body mass index, LBM: lean body mass. *Significant difference compared to pre-training values (p≤0.05).

Strength

There were no significant differences in baseline values between groups in bench press and squat 1RM. Bench press (p=0.001, p=0.001) and squat (p=0.001, p=0.001)1RM values increased significantly, in both groups, after training period. In comparison with the control group, HMB supplementation resulted in a significant greater strength gain in the bench press (p=0.017) and squat (p=0.012) 1RM (figure 1).

Pre and post-training values of anabolic and catabolic hormones of HMB and control groups are shown in table 3.There were no significant differences in baseline values between groups in growth hormone, testosterone, cortisol and the ratio of cortisol to testosterone. Growth hormone (p=0.027, p=0.001) and testosterone (p=0.012, p=0.002) significantly increased and cortisol (p=0.014, p=0.001) and the ratio of cortisol to testosterone (p=0.002, p=0.001) were significantly decreased, in both groups, after the training period. There were no significant differences in the anabolic and catabolic hormonal changes and the ratio of cortisol to testosterone changes between the groups.

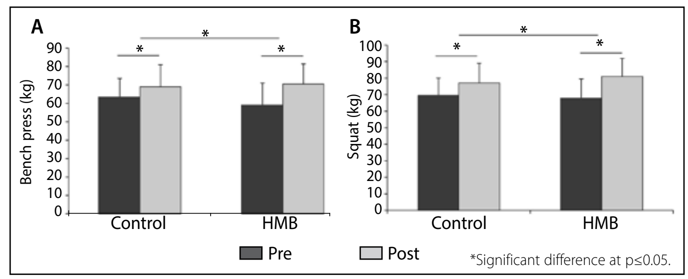

Figure 1. Mean of A) Bench press; B) Squat 1RM;

Table 3. Pre and post-training hormones values.

Variables	Control			HMB		
	Pre	Post	Delta	Pre	Post	Delta
GH (mg/l)	0.9 ± 0.3	1.1 ± 0.2*	0.2 ± 0.2	0.9 ± 0.4	1.2 ± 0.4*	0.2 ± 0.1
Tes (nmol/l)	12.7 ± 1.7	13.4 ± 1.7*	0.7 ± 0.7	12.8 ± 1.2	13.8 ± 1.3*	1.0 ± 0.7
Cor (nmol/l)	289 ± 35	282 ± 33*	-6.9 ± 7.1	307 ± 32	295 ± 33*	-11.9 ± 8.1
C:T	23.1 ± 5.3	21.4 ± 4.6*	-1.7 ± 1.2	23.9 ± 2.5	21.3 ± 2.2*	-2.6 ± 1.4

Values are expressed as mean ± SD; Delta: post-pre values.GH: growth hormone, Tes: testosterone, Cor: cortisol, C:T: ratio cortisol/testosterone. *Significant difference compared to pre-training values (p≤0.05).

DISCUSSION

The present study investigated the effect of HMB supplementation on body composition, muscular strength and anabolic-catabolic hormones after four weeks resistance training in amateur athletes. Our results have shown that HMB supplementation doesn't result in a significant change in body weight, BMI, body fat, LBM and anabolic-catabolic hormones after four weeks resistance training compared to placebo, but resulted in a significantly greater muscular strength gain.

Our findings about the change of body composition after HMB supplementation is consistent with previous studies indicating that supplementation of HMB in conjunction with resistance training has not significant greater effects on body composition in compare to placebo[8,17,22]. It has been suggested that the HMB effect on body composition is inconsequential[23].Some studies reported that HMB was unable to change the body composition of athletes involved in resistance training (22), water polo, rowing[9] or football[17,24].On the other hand, a number of studies failed to confirm these results and indicated that HMB supplementation during 2- to 12-weeks of training promoted significantly greater changes in FFM and fat loss in trained and untrained men and women[4,5,25,26]. Based on previous studies, the data about the effect of HMB supplementation on body composition is inconsistent.

Regarding to strength, the results of our study confirmed the previous findings that HMB supplementation resulted in a significant greater strength gain after training[5,11,22]. Recently, Portal et al.[11] showed that HMB supplementation led to an increase in knee flexion isokinetic force in elite adolescent volleyball players. In the study conducted by Kraemer et al.,[5] bench press and squat 1RM were increased in HMB and control groups after 12 weeks of resistance training. However, the increases in 1RM were significantly greater in the HMB group when compared to the CON group. These results repeated in Thomson et al.[22] study in trained men after 9 weeks resistance training. But these findings are not supported by several investigations[8,9,16,24,27,28].

Changes in strength are largely due to neurological adaptations early in practice (changes in motor unit recruitment, asynchronous to synchronous contractions, etc.), while increases in lean muscle mass, which increases the capacity of the body to produce force, accounts for a greater percentage of strength gain later on[13]. Currently, the ability of HMB to increase indices of strength has been attributed to the changes observed in lean mass. However, to our knowledge, no research has examined possible neurological adaptations facilitated by HMB supplementation. It seems that HMB supplementation may have beneficial effects on neurological adaptations of strength gain.

Previous studies suggested that the beneficial effects of HMB supplementation on performance result from anabolic adaptations and reduced catabolic effects. Therefore, we hypothesized that the beneficial effects of HMB supplementation on strength will be accompanied by an increase in circulating levels of the growth hormone and testosterone, a decrease of cortisol and improvement in the anabolic-to-catabolic hormone ratio. In contrast to our hypothesis, we observed no significant differences in any of these measures between the HMB and placebo groups. These findings are consistent with Portal et al.[11]. These authors reported no significant effect of HMB on growth hormone, testosterone and cortisol after 7 weeks of the training in adolescent volleyball players. Inconsistent with our findings, Kraemer et al.[5] demonstrated that the HMB increased resting testosterone and growth hormone concentrations after 12 weeks of resistance training.

There are several possible reasons for the discrepancy in results observed among studies about the effect of HMB supplementation on body composition, strength and anabolic-catabolic hormones. It is possible that differences in experimental design (e.g., dietary controls, type and intensity of training, subject training status and duration of experiment, etc.), methods employed (e.g., supplement formulations investigated, methods of assessing body composition, strength and hormones), and/or statistical analysis procedures employed among studies may account for some of the differences observed.

In the present study HMB supplementation has no additional effects apart from resistance training on body composition and anabolic-catabolic hormones, but significantly increases muscular strength after four weeks resistance training. It is possible that the duration of HMB supplementation in current study is not sufficient to affect body composition and anabolic-catabolic status in amateur athletes. Increase in strength may be attributed to neurological adaptations.

CONCLUSION

We demonstrated that HMB supplementation in amateur athletes was associated with a greater increase in muscle strength, so that this change was not accompanied by body composition and basal circulating anabolic-catabolic hormonal changes. Whether longer periods of supplementation of HMB are necessary to change body composition and improvement of anabolic-catabolic status during resistance training in amateur athletes remains to be determined. Furthermore, whether HMB supplementation can be beneficial to effects on neurological adaptations also remains to be determined. Further studies are needed to determine the effect of HMB supplementation during resistance training periods in order to optimize its beneficial effects.

All authors have declared there is not any potential conflict of interests concerning this article.

REFERENCES

1. Pinheiro CH, Gerlinger-Romero F, Guimarães-Ferreira L, de Souza-Jr AL, Vitzel KF, Nachbar RT, et al. Metabolic and functional effects of beta-hydroxy-beta-methylbutyrate (HMB) supplementation in skeletal muscle. Eur J Appl Physiol. 2012;112:2531-7.
2. Nissen SL, Sharp RL. Effect of dietary supplements on lean mass and strength gains with resistance exercise: a meta-analysis. J Appl Physiol. 2003;94:651-9.
3. Smith HJ, Mukerji P, Tisdale MJ. Attenuation of proteasome induced proteolysis in skeletal muscle by β-hydroxy-β- methylbutyrate in cancer-induced muscle loss. Cancer Res. 2005;65: 277-83.
4. Nissen SL, Panton L, Wilhelm R, Fuller JC. Effect of β-hydroxy-β- methylbutyrate (HMB) supplementation on strength and body composition of trained and untrained males undergoing intense resistance training. FASEB J. 1996;10:287.
5. Kraemer WJ, Hatfield DL, Volek JS, Fragala MS, Vingren JL, Anderson JM, et al. Effects of amino acids supplement on physiological adaptations to resistance training. Med Sci Sports Exerc. 2009;41:1111-21.
6. Nissen S, Sharp R, Rathmacher JA, Rice D, Fuller JC Jr, Connelly AS, et al. The effect of leucine metabolite β-hydroxy-β- methylbutyrate (HMB) on muscle metabolism during resistance-exercise training. J Appl Physiol. 1996;81:2095-104.
7. Panton LB, Rathmacher JA, Baier S, Nissen S. Nutritional supplementation of the leucine metabolite β-hydroxy-β- methylbutyrate (HMB) during resistance training. Nutrition 2000; 16(9):734-9.
8. Kreider RB, Ferreira M, Wilson M, Almada AL. Effects of calcium β-hydroxy-β methylbutyrate (HMB) supplementation during resistance-training on markers of catabolism, body composition and strength. Int J Sports Med. 1999;20:503-9.
9. Slater G, Jenkins D, Logan P, Lee H, Vukovich M, Rathmacher JA, et al. Beta-hydroxy-beta-methylbutyrate (HMB) supplementation does not affect changes in strength or body composition during resistance training in trained men. Int J Sport Nutr Exerc Metab. 2001; 11:384-96.
10. Slater GJ, Jenkins D. Beta-hydroxy-beta-methylbutyrate (HMB) supplementation and the promotion of muscle growth and strength. Sports Med. 2000;30:105-16.
11. Portal S, Zadik Z, Rabinowitz J, Pilz-Burstein R, Adler-Portal D, Meckel Y, et al. The effect of HMB supplementation on body composition, fitness, hormonal and inflammatory mediators in elite adolescent volleyball players: a prospective randomized, double-blind, placebo-controlled study. Eur J Appl Physiol. 2011;111:2261-9.
12. Eley HL, Russel ST, Baxter JH, Mukerji P, Tisdale MJ. Signaling pathways initiated by beta-hydroxy-beta-methylbutyrate to attenuate the depression of protein synthesis in skeletal muscle in response to cachectic stimuli. Am J Physiol Endocrinol Metab. 2007;293:923-31.
13. Wilson GJ, Wilson JM, Manninen AH. Effects of betahydroxy- beta-methylbutyrate (HMB) on exercise performance and body composition across varying levels of age, sex, and training experience: a review. Nutr Metab. 2008;5:1.
14. Zanchi NE, Gerlinger-Romero F, Guimarães-Ferreira L, de Siqueira Filho MA, Felitti V, Lira FS, et al. HMB supplementation: clinical and athletic performance-related effects and mechanisms of action. Amino Acids 2011;40:1015-25.
15. Pimentel GD, Rosa JC, Lira FS, Zanchi NE, Ropelle ER, Oyama LM, et al. β-Hydroxy-β-methylbutyrate (HMB) supplementation stimulates skeletal muscle hypertrophy in rats via the mTOR pathway. Nutr Metab. 2011;8:11.
16. Hoffman JR, Cooper J, Wendell M, Im J, Kang J. Effects of beta-hydroxy beta-methylbutyrate on power performance and indices of muscle damage and stress during high-intensity training. J Strength Cond Res. 2004;18:747-52.
17. Kreider RB, Ferreira M, Greenwood M, Wilson M, Grindstaff P, Plisk S, et al. Effects of calcium B-HMB supplementation during training on markers of catabolism, body composition, strength and sprint performance. J Exerc Physiol. 3(4):48-59.
18. Decombaz J, Bury A, Hager C. HMB meta-analysis and the clustering of data sources. J Appl Physiol. 2003;95:2180-2.
19. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr. 1978;40:497-504.
20. Brzycki M. Strength testing: Predicting a one-rep max from reps to fatigue. J Health Phys Ed Rec Dance 1993;64:88-90.
21. Gallagher PM, Carrithers JA, Godard MP, Schulze KE, Trappe SW. Beta-hydroxy-beta-methylbutyrate ingestion, part I: effects on strength and fat free mass. Med Sci Sports Exerc. 2000;32:2109-15.
22. Thomson JS, Watson PE, Rowlands DS. Effects of nine weeks of beta-hydroxy-beta- methylbutyrate supplementation on strength and body composition in resistance trained men. J Strength Cond Res. 2009;23:827-35.
23. Rowlands DS, Thomson JS. Effects of beta-hydroxy-beta-methylbutyrate supplementation during resistance training on strength, body composition, and muscle damage in trained and untrained young men: a meta-analysis. J Strength Cond Res. 2009;23:836-46.
24. Ransone J, Neighbors K, Lefavi R,Chromiak J. The effect of betahydroxy beta-methylbutyrate on muscular strength and body composition in collegiate football players. J Strength Cond Res. 2003;17:34-9.
25. Gallagher PM, Carrithers JA, Godard MP, Schulze KE, Trappe SW. β-hydroxy-β methylbutyrate: supplementation during resistance-training. Med Sci Sports Exerc. 1999;31:S402.
26. Fuller NJ, Jebb SA, Laskey MA, Coward WA, Elia M. Four-compartment model for assessment of body composition in humans: comparison with alternative methods and evaluation of the density and hydration of fat free mass. Clin Sci. 1992;82:687-93.
27. Vukovich MD, Slater G, Macchi MB, Turner MJ, Fallon K, Boston T, et al. Beta-Hydroxy-betamethylbutyrate (HMB) kinetics and the influence of glucose ingestion in humans. J Nutr Biochem. 2001;12:631-9.
28. O'Connor DM, Crowe MJ. Effects of six weeks of betahydroxy- beta-methylbutyrate (HMB) and HMB/creatine supplementation on strength, power, and anthropometry of highly trained athletes. J Strength Cond Res. 2007;21:419-23.