β-hydroxy-β-methylbutyrate ingestion, Part I: effects on strength and fat free mass

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ABSTRACT

GALLAGHER, P. M, J. A. CARRITHERS, M. P. GODARD, K. E. SCHULZE, and S. W. TRAPPE. β-hydroxy-β-methylbutyrate ingestion, Part I: effects of strength and fat free mass. *Med. Sci. Sports Exerc.*, Vol. 32, No. 12, 2000, pp. 2109–2115. **Purpose:** The purpose of this investigation was 1) to determine whether HMB supplementation results in an increase in strength and FFM during 8 wk of resistance training and 2) determine whether a higher dose of HMB provides additional benefits. **Methods:** Thirty-seven, untrained, college-aged men were assigned to one of three groups: 0, 38, or 76 $mg \cdot kg^{-1} \cdot d^{-1}$ of HMB (approximately equal to 3 and 6 $g \cdot d^{-1}$, respectively). Resistance training consisted of 10 different exercises performed 3 $d \cdot wk^{-1}$ for 8 wk at 80% of 1-repetition maximum (1RM). The 1RM was reevaluated every 2 wk with workloads adjusted accordingly. **Results:** No differences were observed in 1RM strength among the groups at any time. However, the 38 $mg \cdot kg^{-1} \cdot d^{-1}$ group showed a greater increase in peak isometric torque than the 0 or 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups ($P < 0.05$). The 76 $mg \cdot kg^{-1} \cdot d^{-1}$ group had a greater increase in peak isokinetic torque than the 0 or 38 $mg \cdot kg^{-1} \cdot d^{-1}$ groups at 2.1, −3.15, and −4.2 $rad \cdot s^{-1}$ ($P < 0.05$). Plasma creatine phosphokinase (CPK) activity was greater for the 0 $mg \cdot kg^{-1} \cdot d^{-1}$ versus the 38 or 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups at 48 h after the initial training bout ($P < 0.05$). In addition, no differences were observed in body fat between the three groups. However, the 38 $mg \cdot kg^{-1} \cdot d^{-1}$ group exhibited a greater increase in FFM ($P < 0.05$). **Conclusions:** Although the 1RM strength gains were not significantly different, HMB supplementation appears to increase peak isometric and various isokinetic torque values, and increase FFM and decrease plasma CPK activity. Lastly, it appears that higher doses of HMB (i.e., > 38 $mg \cdot kg^{-1} \cdot d^{-1}$) do not promote strength or FFM gains. **Key Words:** ISOKINETIC, ISOTONIC, FAT FREE MASS, CREATINE PHOSPHOKINASE

Preliminary human studies examining oral β-hydroxy-β-methylbutyrate (HMB) supplementation and skeletal muscle adaptation to short-term resistance exercise suggest an ergogenic benefit (8–11,21). In a 7-wk strength training study of men in their twenties, daily supplementation of HMB in 1.5 $g \cdot d^{-1}$ or 3.0 $g \cdot d^{-1}$ doses increased muscle mass and strength significantly more than nonsupplemented control subjects (10). Specifically, muscle strength increased 13% and 18% with 1.5 $g \cdot d^{-1}$ and 3.0 $g \cdot d^{-1}$ of dietary HMB intake, respectively, compared with the 8% strength gains with no HMB supplementation. In addition, animal studies examining the ergogenic effects of HMB on muscle growth and fat content have demonstrated decreased muscle proteolysis, body fat, and blood cholesterol levels (1,13,14,20).

HMB is produced from the amino acid leucine and its metabolite α-ketoisocaproate (KIC), both of which have been implicated as having anticatabolic effect in both animals (4,18) and humans (16). β-hydroxy-β-methylbutyrate, which is produced from KIC via the enzyme KIC-dioxygenase, may also attenuate muscle breakdown (8). It appears that the majority of HMB is metabolized to β-hydroxy-β-methylglutaryl CoA (HMG-CoA), which can then be employed in cholesterol synthesis (8). HMG-CoA could be rate limiting when cholesterol synthesis is in great demand, such as during periods of rapid cell growth or membrane repair (8). Thus, HMB may provide the necessary amount of HMG-CoA for cholesterol synthesis and subsequent membrane production that may result in decreased muscle damage and quicker recovery during periods of high muscular stress.

To date there is only one published report (10), and several abstracts (9,11), examining the effects of HMB on humans and none examining the effectiveness of a dose higher than 3 $g \cdot d^{-1}$ (i.e., 38 $mg \cdot kg^{-1} \cdot d^{-1}$). The present study was designed to determine the effects of oral HMB ingestion on muscle strength during 8 wk of resistance training and to determine whether a higher dose of HMB (i.e., 76 $mg \cdot kg^{-1} \cdot d^{-1}$ vs 38 $mg \cdot kg^{-1} \cdot d^{-1}$) provided any additional benefits during an eight week progressive total body resistance training study. In addition, the effect of HMB on estimated body composition was examined using a seven-site skin-fold technique. In conjunction with this study, the effects of HMB on hematology and hepatic and renal function during 8-wk of resistance training is reported elsewhere (5).

METHODS

Subjects. Forty-six male subjects volunteered to participate in this study. However, 37 male volunteers aged

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TABLE 1. Subjects characteristics. Included are N, age, height (cm), pre and post weights (kg), pre, post and delta % fat, and pre, post and delta fat free mass (FFM); values are mean ± SE.

	$mg \cdot kg^{-1} \cdot d^{-1}$		
	0	38	76
N	14	12	11
Age	22.3 ± 0.9	21.0 ± 0.9	21.8 ± 1.1
Ht. (cm)	178.8 ± 2.8	180.7 ± 1.6	181.8 ± 2.6
Pre (Kg)	77.2 ± 4.0	76.1 ± 2.7	81.7 ± 5.3
Post (Kg)	77.6 ± 3.8	78.2 ± 2.7	81.8 ± 2.1
FFM (Kg)			
Pre	65.3 ± 2.5	64.4 ± 1.6	69.2 ± 3.0
Post	65.3 ± 2.2	66.3 ± 1.6*	69.0 ± 3.0
Delta	0.0 ± 0.1	1.9 ± 0.6	−0.2 ± 0.5

* Significantly greater increase than the 0 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups ($P < 0.05$).

18–29 completed the 8-wk training program. Seven subjects dropped out of the study before completion due to illness or time commitment. Two subjects were dismissed from the study due to failure to comply with the exercise protocol. Subject characteristics are reported in Table 1. Before any testing the subjects were interviewed by a member of the investigating team and potential subjects were excluded from the study if they engaged in resistance training within the last 3 months or were taking any nutritional supplements. Subjects were also excluded if they smoked or had a history of metabolic, cardiac, and/or pulmonary disease. In addition, the subjects filled out a 3-d dietary recall and those subjects found to be caloric or protein deficient were excluded from the study. All subjects gave written informed consent in accordance with the University's Institutional Review Board before participating in the study.

Experimental design. The subjects were matched based on their body weights and randomly assigned, in a double-blind order, to one of three groups: 0 $mg \cdot kg^{-1} \cdot d^{-1}$, 38 $mg \cdot kg^{-1} \cdot d^{-1}$, or 76 $mg \cdot kg^{-1} \cdot d^{-1}$. These doses approximately corresponded to 0 $g \cdot d^{-1}$, 3 $g \cdot d^{-1}$, or 6 $g \cdot d^{-1}$, respectively, as reported in previous investigations (10,11,21). However, there was an uneven drop-out among the groups which resulted in the differences in mean body weight (Table 1). The HMB and placebo were packaged in identical looking foil packets numbered 1–12. The number corresponded to a group representing the supplement dose and a 10-kg body weight range. Each packet contained one-third of the supplement dose, which the subjects were instructed to mix the contents with 4 oz of water and consume three times per day. The subjects were assigned a group number based on the subject's weight and dosage, which corresponded to the number on the foil packets. To help ensure compliance, the subjects were given their supplement at each workout session and were required to return the emptied foil packets.

Resistance training program and whole body strength evaluation. The subjects attended supervised training sessions three times per week for 8 wk. At least 24-h rest elapsed between training sessions. All training sessions were supervised by a member of the investigation team and the supervisor to subject ratio never exceeded 1:7. Each training session consisted of 10 different exercises: bench press, latissimus pull-down, military press, arm curls, arm extensions, abdominal crunches, hip sled, leg curls, leg extensions, and calf raises. Cybex (Cybex, Inc. Ronkonkoma, NY) weight equipment was used for all exercises, except for arm curls, which were performed seated, using dumbbells. For each of the 10 exercises, the subjects performed three sets of isotonic movement; two sets of 10 repetitions and a final set to failure. All exercises were performed at an intensity of 80% of their predetermined concentric one repetition maximum (1RM). A 1 RM was determined on each of the 10 exercises as the greatest amount of weight that the subject lifted for 1 repetition. Subjects were instructed to rest for 90–120 s between sets. The subjects concentric 1 RM was determined every 2 wk, and the workloads were adjusted accordingly to ensure that the relative intensity remained at 80% throughout the training program (Fig. 1). Volume was also determined during the 8-wk training period. Volume was calculated as the mass lifted, multiplied by the number of repetitions performed and divided by the number of sets performed during each 2-wk period.

Isometric and isokinetic strength testing. The subjects performed four strength evaluations on the knee extensors of the right leg: familiarization session, pretraining, 4 wk (mid) and 8 wk (post) of the training program (Fig. 1). After a 5-min warm-up on a cycle ergometer at a light intensity, the subjects were seated and secured in the Cybex Norm dynamometer (Cybex, Inc. Ronkonkoma, NY). Each test was divided into four parts that were performed in the following order: 1) submaximal and maximal isometric evaluation, 2) concentric isokinetic evaluation, 3) eccentric isokinetic evaluation, and 4) muscular fatigue evaluation. Approximately 2 min of rest was provided between each section.

Maximal isometric contractions. The subjects' knee extensor isometric strength was measured at 60° of knee flexion for a period of 6 s. The subjects were instructed to perform two contractions at maximal effort with a 90-s rest period between contractions. The highest value was used for analysis purposes.

Concentric isokinetic evaluation. To evaluate the force velocity characteristics of the subject's knee extensors, a concentric isokinetic evaluation was performed pre- and post-training. This test involved four warm-up contractions at approximately 50% effort and three maximal repetitions each at velocities of 1.05, 1.58, 2.10, 3.15, 4.20, and 5.25 $rad \cdot sec^{-1}$. The highest value was used for analysis purposes. The subjects were allowed a 30-s rest between warm-up and maximal repetitions and a 90-s rest period between each of the tested velocities.

Eccentric isokinetic evaluation. Similar to the concentric isokinetic contractions, four warm-up and three maximal repetitions were performed at velocities of −1.05, −1.58, -2.10, −3.15, and −4.20 $rad \cdot s^{-1}$. The highest value was used for analysis purposes. The subjects were given a 30-s rest between warm-up and maximal repetitions and a 90-s rest period between velocities for the eccentric contractions.

Fatigue evaluation. Subjects performed four concentric warm-up contractions, followed by 30 maximal isoki-

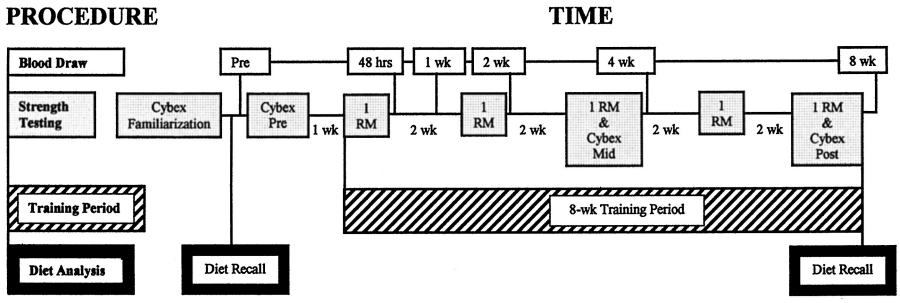

FIGURE 1—Timeline of testing procedures. Including strength testing, blood draws, diet analysis, and resistance training period.

netic concentric contractions at an angular velocity of 2.10 $rad \cdot s^{-1}$. A 20-s rest interval was allotted between the warm-up and maximal contractions. A fatigue index was determined as the percent decline from the contraction with the highest torque value to the contraction with the lowest torque value.

Plasma creatine phosphokinase. Blood samples were taken from the antecubital vein after an overnight fast. Plasma was analyzed for creatine phosphokinase using an enzymatic spectrophotometer assay (Sigma Kit, St. Louis, MO). Three mL of blood was collected in vials containing 0.057 mL of 0.34 molar EDTA (Vacutainer, Franklin Lakes, NJ). Samples were collected before the initiation of the training program and 48 h after the first, 3rd (1 wk), 6th (2 wk), 12th (4 wk), and 24th (8 wk) lifting session. Plasma was extracted and frozen at −80°C until analysis was performed.

Body composition. The subjects' fat free mass was determined using a seven-site skin-fold evaluation with Lange calipers (Cambridge Scientific Industries, Cambridge, MD) by the same tester pre- and post-training for each subject. The following seven sites were used for estimation of body density: chest, triceps, mid-axilla, subscapula, abdominal, suprailium, and thigh. Skin-fold measurements were taken in duplicate and the mean value was used for the determination of body density and fat and lean body mass by using the Brozek and the Jackson and Pollock equations (3,6). A third skin-fold measurement was taken if there was a large discrepancy (i.e., >2 mm) between the initial two measurements.

HMB concentration. Approximately 3 mL of blood plasma was extracted at the following time points for the analysis of HMB: before the initiation of the training program and 48 h after the first, 3rd (1 wk), 6th (2 wk), 12th (4 wk), and 24th (8 wk) lifting session. In addition, a 24-h urine collection was performed during the 6th week of training. This was done at the 6th week as a test of supplement compliance. The volume of urine excreted was measured and a 5-mL sample was transferred into a polystyrene tube and frozen at −80°C until analysis. The blood and urine samples were analyzed for HMB concentration using a gas chromatography (model 6890, Hewlett Packard, Palo Alto, CA) mass spectrometry (model 5973, Hewlett Packard, Palo Alto, CA) procedure as previously described by Nissen et al. (12).

Diets. Subjects consumed their "normal" habitual diet throughout the investigation. A pretraining 3-d dietary recall was performed to ensure each subject was in a proper dietary balance. In addition, a 3-d dietary recall was conducted during the last week of the training period. The dietary recalls were evaluated using a dietary analysis program (ESHA Food Processor, v. 7.0) to determine the subject's nutritional status at the beginning and end of the study.

Statistical analysis. The data were analyzed using the SPSS for windows statistical program (v. 8.0.0). A general linear model (ANOVA) with repeated measures was performed on all variables with the within and between subject factors being time and group (0 $mg \cdot kg^{-1} \cdot d^{-1}$, 38 $mg \cdot kg^{-1} \cdot d^{-1}$, or 76 $mg \cdot kg^{-1} \cdot d^{-1}$), respectively. The alpha level was set at $P < 0.05$. Values found to be significantly different were compared using Bonferroni *post hoc* test. All data are presented as mean ± standard error.

RESULTS

Whole-body strength evaluation. For all three groups the 1-RM steadily increased throughout the 8 wk of resistance training (time, $P < 0.05$). The pre- and post-training 1-RM values for each of the 10 exercises are presented in Table 2. An improvement in strength of 32.5%, 43.5% and 45.5% was observed in overall 1RM strength during the 8-wk training period for the 0, 38, and 76 $mg \cdot kg^{-1} \cdot d^{-1}$, respectively. No differences between groups were observed in the increase in 1-RM in any of the 10 exercises (bench press, arm curls, arm extension, military press, latissimus pull-down, abdominal crunches, hip sled, leg curls, leg extensions, and calf raises).

Training volume. The volume lifted by each group increased at 2-wk intervals throughout the 8-wk training program (time, $P < 0.05$). Volume was calculated as the mass lifted, multiplied by the number of repetitions performed and divided by the number of sets performed during each 2-wk period. No differences in volume were observed between groups when expressed as $kg \cdot reps \cdot set^{-1}$ or relative to body weight as $kg \cdot reps \cdot set^{-1} \cdot kg_{bw}^{-1}$ (Fig. 2).

Isometric and isokinetic strength testing. The pre- and post-training force-velocity curves are presented in Figure 3. All three groups improved at each velocity (time, $P < 0.05$). At 0 $rad \cdot s^{-1}$ the 38 $mg \cdot kg^{-1} \cdot d^{-1}$ group improved 32% from 254 N·m to 335 N·m, which represented a greater improvement than the 0 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ group (group × time, $P < 0.05$). There were no differences at the following velocities among all three groups: concentric: 1.05, 1.58,

TABLE 2. Pre- and post-training 1 RM measurements (kg) for ten exercises.

	Pretraining ($mg \cdot kg^{-1} \cdot d^{-1}$)			Posttraining ($mg \cdot kg^{-1} \cdot d^{-1}$)		
Exercise	0	38	76	0	38	76
BP	66.6 ± 1.0	67.0 ± 1.5	81.8 ± 1.6	85.2 ± 1.3	80.0 ± 2.3	101.5 ± 1.9
AC	16.2 ± 0.2	16.1 ± 0.2	18.4 ± 0.3	19.3 ± 0.3	17.6 ± 0.5	22.1 ± 0.3
AE	35.1 ± 0.7	34.1 ± 0.5	38.5 ± 0.7	49.5 ± 0.7	46.2 ± 1.4	53.9 ± 0.7
SP	47.5 ± 0.7	44.9 ± 0.6	52.3 ± 1.0	58.1 ± 0.9	56.8 ± 0.8	66.8 ± 1.2
LP	67.8 ± 0.7	66.3 ± 0.5	73.9 ± 1.3	84.8 ± 0.7	80.0 ± 2.2	92.5 ± 0.9
AbC	57.2 ± 0.8	56.3 ± 0.7	56.3 ± 0.6	76.7 ± 0.7	78.3 ± 0.9	75.2 ± 0.8
HS	204.4 ± 5.8	187.8 ± 5.4	230.7 ± 7.0	299.9 ± 8.5	292.9 ± 8.0	354.3 ± 12.1
LC	66.6 ± 0.9	62.2 ± 0.9	65.3 ± 1.2	80.2 ± 0.9	82.3 ± 1.2	78.5 ± 1.1
LE	85.6 ± 1.2	85.7 ± 0.9	94.0 ± 1.6	114.2 ± 1.2	103.5 ± 35.2	123.3 ± 2.3
CR	168.2 ± 3.0	153.6 ± 3.6	174.5 ± 1.8	224.1 ± 2.7	214.5 ± 4.0	231.0 ± 1.1

BP, bench press; AC, arm curls; AE, arm extensions; SP, shoulder press; LP, latisimus pulldown; AbC, abdominal crunches; HS, hip sled; LC, leg curls; LE, leg extensions; CR, calf raises; values are mean ± SE.

3.15, 4.20, and 5.25 $rad \cdot s^{-1}$; eccentric: −1.05, -1.58, and −2.10. However, the 76 $mg \cdot kg^{-1} \cdot d^{-1}$ group improved greater than the 0 or 38 $mg \cdot kg^{-1} \cdot d^{-1}$ groups at the following concentric and eccentric velocities: 2.10, and −3.15 and −4.20 $rad \cdot s^{-1}$ (group × time, $P < 0.05$).

Fatigue evaluation. The pre- and post-training fatigue index and the amount of work performed during the fatigue evaluation for the three groups are presented in Table 3. All three groups improved in the amount of work conducted during the test from pre to mid and mid to post training (time, $P < 0.05$). No differences were observed in the improvements of either percent fatigue or total work done between the groups.

Plasma creatine phosphokinase. The plasma CPK values are represented in Figure 4. The CPK values taken 48 h after the initial exercise bout were increased in the 0 $mg \cdot kg^{-1} \cdot d^{-1}$ group compared with the 38 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups (group × time, $P < 0.05$). No other CPK values were found to be different between the groups.

Body composition. Changes in body composition are presented in Table 1. No differences were observed in percentage of body fat between the three groups. Although, the 38 $mg \cdot kg^{-1} \cdot d^{-1}$ group demonstrated a greater increase in FFM (1.9 kg) from pre- to post-training than the 0 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups (group × time, $P < 0.05$).

HMB concentration in plasma and urine. The concentration of HMB in the plasma and urine increased as the amount of HMB ingested increased. The plasma HMB concentrations ranged from 1.9 to 3.4, 22.9 to 43.7, and 23.7 to 66.6 nmol·mL for the 0, 38, and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups, respectively. Approximately 20% and 25% of the HMB was recovered in the urine of the 38 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$ groups, respectively.

Dietary analysis. An estimation of the caloric intake and grams of carbohydrate, fat, protein, and leucine ingested per day during the pretraining period and during the 8th week of training are presented in Table 4. None of the dietary variables were found to be different over time or among the three groups.

DISCUSSION

Previous research has shown that HMB supplementation during intense resistance exercise results in an increase in muscular growth and concomitant increase in strength (9–11,21). The primary finding of this investigation was that HMB supplementation elicited no differences in 1 RM strength compared with the placebo group. However, the higher dose of HMB (i.e., 76 $mg \cdot kg^{-1} \cdot d^{-1}$) elicited a greater increase in concentric peak torque at 2.1 and eccentric peak torque at −3.15, and −4.2 $rad \cdot s^{-1}$. Also, the group that consumed 38 $mg \cdot kg^{-1} \cdot d^{-1}$ of HMB had a greater increased FFM gains greater than the other two groups (0 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$).

In contrast to previous human studies examining the interaction of strength gains and HMB, the majority of the strength data in the present investigation exhibited no differences among either HMB groups (38 and 76 $mg \cdot kg^{-1} \cdot d^{-1}$) and the placebo group (Tables 2 and 3 and Figs. 2 and 3). The lack of significance could be explained, in part, from the differences in methodology. For example, the present study employed an 8-wk training period with subjects performing 3 sets at 80% 1 RM. The training period was half as long (4 wk) in the majority of the other studies (9–11).

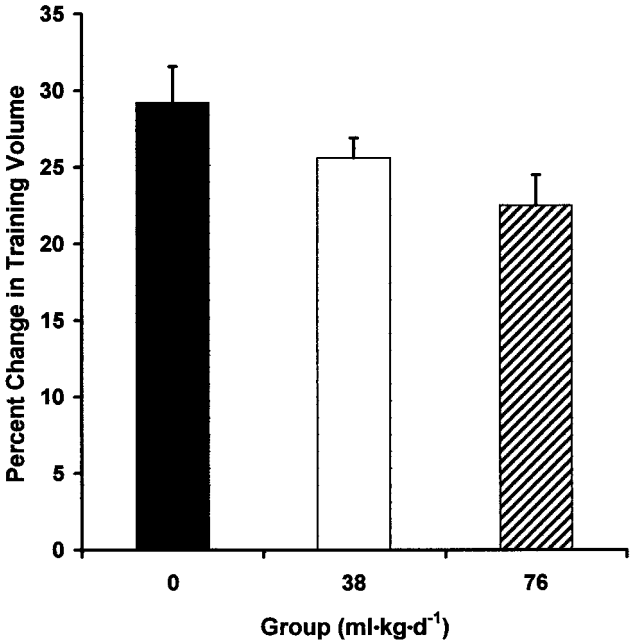

FIGURE 2—Percent change in training volume from the first 2-wk period (0–2 wk) to the last 2-wk period (6–8 wk).

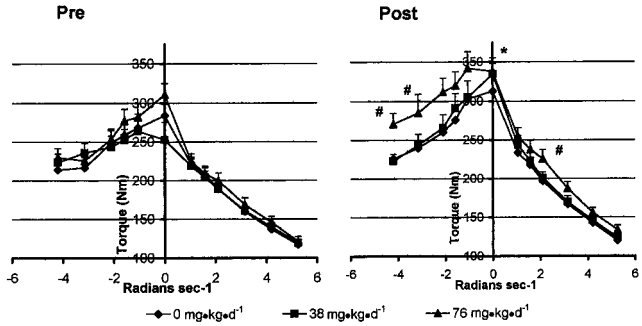

FIGURE 3—Pre- and post-training force-velocity relationship of the right knee extensor. Each point represents group means. Standard errors expressed as error bars. * Significantly greater increase, pre to post, than 0 and 76 $mg^{-1}\cdot kg^{-1}\cdot d^{-1}$ ($P < 0.05$). # Significantly greater increase, pre to post, than 0 and 38 $mg^{-1}\cdot kg^{-1}\cdot d^{-1}$ ($P < 0.05$).

Nissen et al.(10) found that supplementation of 3 $g\cdot d^{-1}$ significantly increased total body strength over a period of 3 wk in untrained male subjects. In addition, the subjects performed 5 sets for each exercise; 2 warm-up sets of 10 repetitions and 3 sets at 90% 1 RM. The lower intensity (80% vs 90%) of the present investigation may produce dissimilar results to the previous study (10). Two other studies that employed shorter training periods (4 wk) found significantly greater increases in the amount of weight lifted during the bench press for trained and untrained male (11) and untrained female subjects (9) with HMB supplementation (3 $g\cdot d^{-1}$). It could be argued that HMB is most beneficial during the initial training period. However, the present study did not demonstrate significant changes in strength with HMB supplementation at any of the 2-wk interval time periods including 4 wk. In addition, it has been shown that the initial strength gains associated with resistance training are mostly due to neural adaptations (15). At mid-testing (4 wk), all three groups elicited an increase of similar magnitude in strength in all tested strength variables.

Several studies examining the effects of HMB and resistance training have employed training periods of similar length to the present investigation; however, the sample groups were dissimilar (10,21). Nissen et al.(10) found significantly greater increases in the amount of weight lifted in the bench press as a result of HMB supplementation (3 $g\cdot d^{-1}$, similar to 38 $mg\cdot kg^{-1}\cdot d^{-1}$) during 7 wk of resistance training. In contrast to the present study, the subjects were previously trained and were exercising 6 $d\cdot wk^{-1}$. Another study employing older adults (mean age 70 ± 1 yr), found that HMB supplementation resulted in a significantly greater increase in lower body strength over an 8-wk training period compared with placebo (21). The subject population employed in the present study was untrained college-aged males. Thus, training status and age may have an impact on whole muscle strength during ingestion of moderate doses of HMB.

In the present investigation all three groups increased in training volume ($P < 0.05$, time); however, no differences were observed among the three groups (Fig. 3). This finding contrasts the results of the only other investigation examining the interaction of HMB and volume of training performed (10). Nissen et al.(10) found a 5–10% increase in training volume, what is referred to as muscle strength in the article, with HMB supplementation in untrained college-aged males. As mentioned in the previous paragraphs, the dissimilar results may be due to differences in length of training (3 vs 8 wk), or intensity of training (90% vs 80% 1RM).

No other investigations have examined the effects of HMB and resistance training on the whole muscle force-velocity relationships (Fig. 2). The present investigation found that the higher dose of HMB (i.e., 76 $mg\cdot kg^{-1}\cdot d^{-1}$) produced greater improvements in knee extensor peak torque than the 0 or 38 $mg\cdot kg^{-1}\cdot d^{-1}$ groups at the faster eccentric velocities (−3.15, and −4.20 $rad\cdot s^{-1}$). Also, the 76 $mg\cdot kg^{-1}\cdot d^{-1}$ group elicited a greater improvement in peak torque compared to the other two groups at a concentric velocity of 2.10 $rad\cdot s^{-1}$. The velocity of an isotonic contraction of the knee extensors, at 80% 1 RM, was measured in four subjects and determined to be approximately 2.6 $rad\cdot s^{-1}$. Thus, the velocity at which the subjects were training at may partially account for the increase in peak torque at 2.1 $rad\cdot sec^{-1}$. In addition, the 38 $mg\cdot kg^{-1}\cdot d^{-1}$ group elicited a greater increase in maximal isometric strength compared with the other two groups. No other velocities were shown to be significantly different between the groups.

Lower CK levels at 48 h were observed in the 38 and 76 $mg\cdot kg^{-1}\cdot d^{-1}$ compared with the other two groups, indicating that HMB may have partially inhibited muscle breakdown (Fig. 4) (2). Acknowledging the limitations of muscle damage estimation via plasma CK (7,19), these results are similar to a previous study suggesting that HMB may partially attenuate muscle protein breakdown (10). Nissen et al.(10) found that HMB supplementation elicited a significant decrease in urinary 3-methyl-histidine, but no significant decreases in plasma CK and lactate dehydrogenase levels compared with a control group.

Previous studies have demonstrated significant increases in FFM as a result of HMB supplementation. The group ingesting 38 $mg\cdot kg^{-1}\cdot d^{-1}$ elicited a greater (1.9Kg) increase in FFM compared with 0 or 76 $mg\cdot kg^{-1}\cdot d^{-1}$. The other two groups (0 and 76 $mg\cdot kg^{-1}\cdot d^{-1}$) showed no increase in FFM (Table 1). Therefore, the present results and the results of previous investigations (10) suggest that moderate levels of HMB supplementation (i.e., 38 $mg\cdot kg^{-1}\cdot d^{-1}$) may induce increases in FFM during a period of intense training. It is unclear why the group ingesting moderate amounts of HMB

TABLE 3. Total work done (J) and percent fatigue pre- and post-training during 30 maximal concentric isokinetic contractions at 2.1 $rad\cdot s^{-1}$; values are mean ± SE.

	Dosage		
	0 $mg\cdot kg\cdot d^{-1}$	38 $mg\cdot kg\cdot d^{-1}$	76 $mg\cdot kg\cdot d^{-1}$
Work done			
Pre (J)	5347 ± 234	5625 ± 251	5717 ± 304
Post	5670 ± 238	5983 ± 149	6312 ± 305
% Change	6%	6%	10%
% Fatigue			
Pre	53.8 ± 2.5	51.0 ± 2.7	51.2 ± 2.0
Post	54.7 ± 2.0	50.2 ± 3.3	52.1 ± 2.2

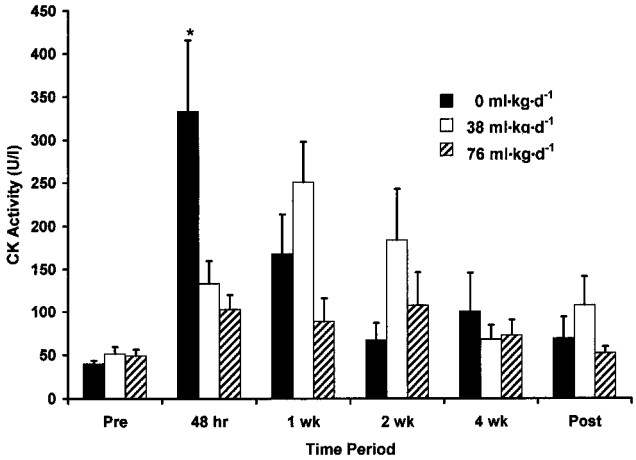

FIGURE 4—Plasma creatine kinase activity throughout the training period expressed as $U \cdot L^{-1}$ at 25°C. Standard errors expressed as error bars. * Significantly greater increase in creatine kinase activity than 38 or 76 $mg^{-1} \cdot kg^{-1} \cdot d^{-1}$, from pretraining values.

(38 $mg \cdot kg^{-1} \cdot d^{-1}$) showed greater increases in FFM than the group ingesting higher amount of HMB (76 $mg \cdot kg^{-1} \cdot d^{-1}$). It should be noted that in the current investigation, skin-fold measurements were employed to estimate body fat; thus, limiting the conclusions that can be drawn from the body composition data.

It has been demonstrated that plasma levels of HMB increase with greater amounts of ingestion up to 3 $g \cdot d^{-1}$ (22). A study using porcine and sheep has determined that the half-life of HMB appears to be approximately 2 h and 3 h, respectively (17,22). Therefore, the timing of HMB ingestion may influence the results of the present study. The subjects in the current investigation consumed their supplement three times, spread out though each day. Normal plasma HMB concentration in porcine range from 1 to 4 μM (22). In the present study, plasma HMB concentration in the 0 $mg \cdot kg^{-1} \cdot d^{-1}$ group ranged from 1.85–3.4 $nmol \cdot mL^{-1}$ and HMB supplementation increased plasma HMB concentrations 10- to 20-fold times the 0 $mg \cdot kg^{-1} \cdot d^{-1}$ group values. It has been demonstrated that up to one half of ingested HMB is excreted in the urine (8). Approximately 20–25% of the HMB was excreted in the urine of the subjects participating in the current study. To date, no direct research has shown that human muscles absorb HMB from the blood. Telleyrand et al.(17) demonstrated that porcine muscle does not absorb HMB except in very low concentrations. Thus, it may be that skeletal muscles are unable to uptake higher doses of HMB, which may partially explain the lack of changes seen in FFM and 1RM values in the (76 $mg \cdot kg^{-1} \cdot d^{-1}$).

TABLE 4. Pre- and post-dietary composition: total calories consumed and protein intake per day; values are mean ± SE.

	Dosage		
	0 $mg \cdot kg \cdot d^{-1}$	38 $mg \cdot kg \cdot d^{-1}$	76 $mg \cdot kg \cdot d^{-1}$
Calories			
Pre	2505 ± 112	2855 ± 111	2871 ± 371
Post	2572 ± 141	3145 ± 281	2787 ± 204
Carbohydrate (g)			
Pre	351 ± 22	381 ± 21	422 ± 37
Post	306 ± 8	436 ± 19	397 ± 20
Fat (g)			
Pre	80 ± 5	104 ± 6	92 ± 8
Post	102 ± 13	108 ± 14	99 ± 8
Protein (g)			
Pre	89 ± 5	103 ± 10	85 ± 8
Post	108 ± 11	92 ± 6	100 ± 10
Leucine (g)			
Pre	5.7 ± 0.6	3.1 ± 0.4	3.0 ± 0.4
Post	3.8 ± 0.7	3.7 ± 0.6	4.0 ± 0.4

In summary, although all groups improved in 1RM strength during the 8-wk resistance training program ($P < 0.05$), no differences were observed between group. Thus, these data indicate that HMB ingestion may not promote additional 1RM strength gains during an 8-wk high-intensity resistance training program. However, a higher dose of HMB (i.e., 76 $mg \cdot kg^{-1} \cdot d^{-1}$) elicited a greater increase in peak torque at 2.10 and at −3.15, and −4.20 $rad \cdot s^{-1}$. Additionally, moderate levels of HMB supplementation has been shown to lower plasma CK levels during the early phases (48 h) of high-intensity strength training and may enhance gains in FFM. It also appears that a higher dose of HMB (>38 $mg \cdot kg^{-1} \cdot d^{-1}$) may attenuate the early phase plasma CK levels but does not appear to promote 1 RM strength or FFM gains. These data are specifically applicable for untrained younger men. Further investigations are needed to determine the effectiveness of HMB as an ergogenic aid. As stated earlier, age, training status and/or variations in protocol may have accounted for the discrepancies in this study compared to previous investigations.

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