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Research Article

THE EFFECTS OF BRANCHED-CHAIN AMINO ACID SUPPLEMENTATION ON DELAYED ONSET MUSCLE SORENESS IN PEOPLE WITH DIABETES

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A B S T R A C T

For individuals with diabetes, exercise is important for maintaining proper glycemic control. However, exercise induces muscle soreness, making it problematic for these individuals to maintain exercise regimes. In younger non-diabetic individuals, studies have shown that nutritional supplementation including branched chain amino acids (BCAA), enhance muscle recovery. The purpose of this blinded study was to assess the effects of BCAA supplementation on delayed onset muscle soreness (DOMS) in diabetics compared to healthy controls. Forty-four subjects; 28 healthy, and 16 with diabetes, were randomly assigned to either the BCAA or placebo group. Measurements including muscle strength, electromyography response of the biceps muscle during maximum effort, perceived soreness, serum myoglobin concentration, elbow range of motion, and skin temperatures were collected before the biceps exercise session and for the five following days. The results showed that while serum myoglobin concentrations increased at 48 hours for both the healthy and diabetic subjects, it was significantly higher($P = 0.013$) in the diabetic subjects who took the placebo supplement (pre-exercise = 54.5 +/- 8 ng/mL, 48 hours = 767.1 +/- 189 ng/mL) when compared to those who took the BCAA supplement (pre-exercise = 51.4 +/- 7 ng/mL, 48 hours = 158.1 +/- 62 ng/mL). Pain was 79.6% higher in the diabetic group who took the placebo when compared to the BCAA group ($P = 0.017$). In conclusion, BCAA supplementation reduced muscle damage and muscle soreness in diabetic subjects, whereas they had minimal effects on the healthy control subjects.

INTRODUCTION

The diabetes epidemic is on the rise in both developing and developed countries[1,2]. According to the World Health Organization (WHO) and recent estimates, the disease now affects approximately 345 million people worldwide and is expected to affect around 440 million by 2030, representing almost 8% of the global adult population [3,4]. Lifestyle characteristics such as obesity, a sedentary lifestyle, and lack of physical activity are regarded as the most important risk factors, both independently associated with diabetes and diabetes related co-morbidities[5,6].

Exercise is considered a major cornerstone of diabetes management. Studies have shown that exercise is recommended as part of the treatment and prevention of type 2 diabetes mellitus (T2DM) [7,5,8]. Even though aerobic exercise has beneficial effects for managing and treating T2DM, it has been found that resistance-type exercise is also effective in controlling blood glucose, and in reducing Hemoglobin A1c (HbA1c) levels [7,9-11]. It is best for individuals with diabetes to participate in a combination of both aerobic and resistance exercise to properly manage their blood glucose levels.

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The effects of combined exercise have shown more pronounced outcomes on glycemic control, muscle strength, and insulin sensitivity [7,9,12]. A study done by Church and colleagues [9], showed that a combination exercise group decreased their diabetes medication dependency, when compared to a control group who had increased their use of diabetes medications. It would be imperative then, to include resistance training as a primary step in the exercise schedule of a diabetic patient. This is particularly important for obese individuals, since aerobic exercise may be challenging for them.

Resistance training would be more beneficial for individuals with diabetes to begin with, as it contributes to the recruitment of previously inactive muscle fibers, which would enhance the quality of the muscle, and lead to gains in muscle mass[13,7,14]. This would result in increased whole body insulin sensitivity, and improved glucose control[13,7,5].

Delayed onset muscle soreness (DOMS) however, is a phenomenon that occurs in skeletal muscle as a result of novel or unaccustomed exercise [15-17]. The severity of the damage and the extent of discomfort is exacerbated over time, and occurs minutes to days after the acute exercise bout[15,16].The intensity of the symptoms and discomfort associated with DOMS usually peaks between 24 to 72 hours post exercise,

and can last for up to 10 days, especially when the exercise bout encompasses an eccentric component [17-19]. Activities that are comprised of repeated eccentric contractions have been shown to result in damage to the ultrastructure of skeletal muscle [20,21]. This damage manifests itself as a temporary decrease in muscle function, restricted range of motion in the associated joint, increased muscle soreness, an increased swelling of the involved muscle group, and an increase in intramuscular proteins in blood such as creatine kinase, and myoglobin [22,23,20]. Consequently, DOMS is considered one of the most common recurrent forms of injury, which can lead to further injuries if a premature return to exercise is attempted [16]. For this reason, pain associated with DOMS can reduce an individual's willingness to exercise.

Not much is known about DOMS in people with diabetes. However, Studies have shown that older individuals have reduced proteolytic activity and an elevated production in free radicals [24,25]. This elevation in free radicals prolongs healing time after excessive exercise[24]. With higher levels of free radicals, metabolic impairments, and endothelial dysfunction in people with diabetes [26,27], DOMS has been found to be more severe in this population [26,28].

As a result of these observations, methods to alleviate the severity of DOMS, and to minimize the damage resulting from resistance exercises have been investigated. Treatment strategies including massage (depending on the time and type of massage) [29-31], water baths [32,33], and the administration of non-steroidal anti-inflammatory drugs (NSAID) [34-36] have shown varying results. Other treatment strategies such as cryotherapy, stretching, homeopathy, and ultrasound have shown minimal to no effect on the improvement of muscle soreness [15,37,38,16,39,40]. However, inregards to acute nutritional interventions, there is evidence that suggests ingesting protein supplements which are high in branched chain amino acids (BCAA) can attenuate muscle damage, reduce muscle soreness, and promote enhanced recovery of muscle function[41,22,23].

Resistance exercise causes decreases of some of the essential amino acids, including BCAA, during the recovery period after the exercise [42,43]. Resistance exercise then, alters the turnover of muscle protein by increasing the amino acid transport within the muscle [43]. This enhances both the rates of skeletal muscle protein synthesis, and protein breakdown during the recovery period following even a single bout of exercise [44,43]. Skeletal muscle however, remains in an overall catabolic state unless muscle protein synthesis surpasses muscle protein degradation, and for this to take place, adequate nutritional intervention is necessary during this recovery period [44,45]. Thus, when essential amino acids (EAA) are ingested in conjunction with an acute bout of resistance training, the hypertrophic response is enhance resulting in a net increase in muscle protein synthesis, thereby improving performance [22,46].

Among these EAA, exceptional results have been observed with BCAA, and specifically leucine [46,47]. Studies have indicated that BCAA are mainly used by active skeletal muscles during sub maximal exercise, whereas most other amino acids are metabolized in the liver [42,48].

Recent findings suggest that BCAA can be safely consumed in large doses with no adverse effects in healthy adults, when compared to other amino acids in protein [49,50]. Furthermore, the ingestion of acute doses of BCAA supplements containing all 3 BCAA (leucine, isoleucine, and valine) appears to be well tolerated by adults, because human cells have a tightly controlled enzymatic system for BCAA degradation [50,47].

Numerous studies have investigated the effects of BCAA supplementation on skeletal muscle soreness. Some found that BCAA may be useful for muscle recovery following acute sessions of exercise, both in trained and untrained individuals [22,51,45,52,23]. In contrast, other studies showed no effects of BCAA ingestion on DOMS [53,46]. However, no study to date has assessed the effectiveness of BCAA supplements on DOMS in a diabetic population. Thus, the purpose of this study was to examine the effectiveness of BCAA supplementation on reducing DOMS. We hypothesized that BCAA supplementation would be beneficial in alleviating DOMS by reducing muscle damage, and maintaining the functional performance of the exercised muscle.

SUBJECTS AND METHODS

Forty four subjects participated in this study. There were 2 groups, one group of healthy individuals which consisted of 28 subjects, and another group of 16 diabetic subjects. The participants in these 2 groups were randomly assigned into either the experimental group, who ingested the BCAA supplement, or the placebo group. All the subjects were physically inactive for at least 3 weeks prior to participating in the study. Subjects were excluded if they were pregnant, had hepatic diseases, were diagnosed with Rhabdomyolysis, or an impaired circulatory disease (such as Raynaud's), had any recent upper limb injuries, had severe neuropathies in their upper limbs, were hypertensive (blood pressure over 145/95 mmHg), or were on high doses of alpha or beta agonist/antagonists, Cox 2 inhibitors, calcium channel blockers, or pregabalins. Also, subjects were advised not to take any pain reducers, NSAID, or dietary supplements during the course of the study. The average age, height, weight, and demographics of the subjects Table 1. Subjects were informed of all experimental procedures and protocols and signed a statement of informed consent.

Study Design

This study was a double blinded randomized controlled trial. The subjects and the examiners were blinded to the supplement taken, and the subjects were randomly allocated into either the experiment group, or the placebo group. All measurements were taken at 6 time periods: a baseline measurement taken pre-exercise (baseline), and post-exercise measurements at 30 minutes (day1), 24 hours (day2), 48 hours (day3), 72 hours (day4), and 96 hours (day5). The serum myoglobin measurements were taken at 5 occasions, where all measurements were taken at the same time periods except for day2 (at 24 hours).

The Supplement Protocol

The subjects in the experimental group took 3 doses of the BCAA supplement. The first dose was taken 30 minutes before the workout, the 2nd dose was taken immediately after completing the workout, and the 3rd dose was taken on the 2nd day (24 hours post exercise). The amount of BCAA supplement administered to the subjects in the experimental group on day 1 was a total dose of 1 gram of BCAA per kilogram of lean body mass (a bioelectric impedance analyzer

was used to measure lean body mass as described below). This dose was divided in half and administered at the two specified occasions for the 1st day. The 3rd dose (on day 2) was equivalent to 0.8 grams per kilo of lean body weight, and was administered before any measurements were taken on that day. The ratio of isoleucine, leucine, and valine used in this study was 1:2.5:1 respectively. The subjects in the placebo group were administered 3 doses of a placebo supplement at the exact same times as above. The placebo supplement consisted of cellulose powder, which has no effects on skeletal muscle. Both the BCAA and the placebo supplement were mixed in a low calorie fruit flavored drink. The tastes of both the BCAA and placebo drinks were identical. Two teaspoons of artificial sweetener was added to both supplements to mask the slight bitterness of the supplements.

The Resistance Maximum (RM) and Muscle Strength (MS) Testing

A strength measuring device with 4 strain gauges placed on opposite sides of a steel bar (arranged as a Wheatstone bridge) was used to measure each individuals resistance maximum (RM) and muscle strength (MS). When the bar bends, the strain gauges get deformed and an electrical output is provided. This device was interfaced with a computer through a BioPac (DAC-100) bioelectric amplifier module (BioPac Systems, Goleta, CA). This module was connected to a BioPac MP-150 analog to digital converter sampling at a frequency of 1,000 Hz per second, and at a resolution of 24 bits. The output signal was amplified 5,000 times. Data analysis and storage was done with Acknowledge 9.1 software from BioPac (BioPac Systems, Goleta, CA). This method has also been described elsewhere [28].

The device was fixed to a bench at a 45° angle, so that only the biceps would be recruited. Subjects sat behind this bench with their intended arm aligned to the device. The strap attached to the strain gauge device was placed on the subject's wrist, and an examiner instructed each subject when to exert their maximal force and when to relax (Fig.1). Strength was determined on 3 occasions with each contraction being 3 seconds in duration and approximately 1 minute apart. The average of these 3 measurements was considered their maximum strength. The baseline (pre-exercise) MS measurement was also considered the subjects' RM. After determining the RM for the biceps muscle of each subject, the intended session of exercise was done with 35% of their RM.

Electromyography (EMG) Assessment

Surface EMG was recorded from the exercised biceps muscle and sampled by 2 bipolar vinyl adhesive EMG electrodes with an active surface area of 0.5 cm^2. One electrode was placed on the mid-belly of the biceps brachii muscle and the other electrode was placed immediately distal to it. The position of both electrodes was immediately marked with permanent ink to ensure consistent placement on subsequent testing days. The ground electrode was attached to the forearm, and the position was also marked with permanent ink. The electrodes were connected to a BioPac (EMG-100B) electromyogram amplifiermodule (BioPac Systems, Goleta, CA), which was interfaced with a computer. This module was connected to a BioPac MP-150 analog to digital converter. The raw EMG signal was collected at a frequency of 1,000 Hz per second, at a resolution of 24 bits, and amplified 5,000 times. Before recording, signals were visually inspected to ensure back groundnoise and artifacts were minimized. The EMG measurements were standardized in that all measures were taken during the MS measurements. The EMG readings were recorded at the same time the subjects were instructed to contract their muscles for the MS measurement.

Soreness/Pain Measurements

The short form McGill pain questionnaire (SF-MPQ) has been identified as a reliable measure of pain [54,55], and was used to assess subjective soreness of the arm muscles on all days of the experiment. The benefit of this scale over the typical visual analog scale is that this scale is divided into 4 simple sections (a sensory pain rating index, an affective pain rating index, a present pain intensity rating, and an evaluative overall intensity of total pain), which gives a better overview of the type and intensity of the perceived pain. The subject splaced a check mark on the appropriate columns of each type of pain, to indicate their response to soreness.

Relaxed Elbow Range of Motion (RROM)

Measurements of elbow resting angles were assessed using a universal goniometer with subjects positioned in a standardized manner. During all the measurements, the subjects were sitting in an armless chair so that they sat in an erect position with the trunk supported and the feet on the floor. The arm, shoulder, and trunk were maintained in a neutral position throughout testing. The lines of the humerus and radius were used as standardization points. The lateral epicondyle of the humerus was considered the goniometric axis of movement, and was marked with a semi-permanent pen on all subjects. The reliability of this measurement technique has been demonstrated [56]. The range of motion measured for the purpose of this study was the elbow angle at rest, taken as the angle of the elbow while the arm hung loosely by the subjects side. Each measurement was repeated 3 times, and the average of all 3 measurements was the final measurement used. All measurements were obtained by the same experimenter, using the same goniometer, in order to minimize any measurement error.

Blood Sampling & Measurement of Serum Myoglobin Concentrations

Approximately 4 mL peripheral blood was collected from an antecubital vein. Peripheral venous blood was drawn on all days of the experiment, except day 2. The blood was allowed to clot at room temperature for 10 minutes, before it was spun down in a refrigerated centrifuge at 4000 rpm for 10 min to separate the serum from the cells. The serum samples were then stored at -80°C until the analyses was done.

Serum myoglobin was determined using a TOSOH "AIA®-360" automated enzyme immunoassay analyzer (TOSOH Corp., Tokyo, Japan). The myoglobin Assay kits (Myo 025297, ST AIA-PACK Myoglobin) were used according to the manufactures instructions. Controls were run before and after each assay session, to verify that the measurements were accurate and within the manufacturers specified quality control ranges. The normal reference range for myoglobin using this method was 31.4 - 971 ng/mL. The intra-assay and inter-assay coefficient of variations were 2.76 %, and 4.45 % respectively.

Skin Temperature

Skin temperature was measured using a Flir TC660 Thermal Camera (Stockholm, Sweden). The thermal image taken of the exercised arm was taken from approximately 1 meter away, and perpendicular to the skin. From a series of tests done at our labs using the FLIR 660 IR Camera, this distance and angle were found to have the best correlation (r = 0.93) with thermocouple readings. The images were taken in a temperature controlled room which was maintained at approximately 23°C (+/- 0.5°C). The temperatures from the acquired image were measured at 4 locations on the skin above the biceps muscle using the "Thermo Vision® Examin IR™" software Version: 1.10.2. These 4 readings were analyzed individually and then averaged to give a full perspective of the temperature above the exercised muscle.

Lean Body Weight Determination

Lean body weight was determined by electrical impedance with an RJL Systems Quantum 2 Bioelectric Impedance Analyzer (Minneapolis, MN). The unit measured resistance and reactance with 1.0 ohms of resolution. Four electrodes were placed on the body, two source electrodes on the hand and foot and two recording electrodes on the hand and foot. The system placed a current of approximately 0.1 milliamps at 100,000 cycles per second frequency, through the source electrodes. The recording electrodes recorded the signal transmitted through the body, and use this to calculate body fat content via the software provided by the manufacturer (RJL Systems). The Quantum 2 with the multiplexed cable, allows multi-zone and segmental measurements to be taken quickly and easily in 26 segments to calculate body water and body fat.

Food Dietary Analysis

Diet was assessed at baseline using the Brief Block Food Frequency Questionnaire (FFQ) (Block Dietary Data Systems, Berkeley, CA, www.nutritionquest.com) . This questionnaire has been shown to be a valid tool for assessing different types of nutritional components [57,58].

Procedure

First, demographical data was collected including: height, weight, age, body fat, body mass index (BMI), blood pressure, and medical history. Also, baseline data of all the previously indicated measurements were collected (MS, EMG, SF-MPQ, and RROM), including blood samples for the myoglobin measurement, and the administration of the brief FFQ. The initial dose of the supplement, whether BCAA or placebo, was also administered at this time. The targeted muscles for this experiment were the elbow flexors. The resistance exercise was performed using a dumbbell, and DOMS was only induced in the subjects' dominant arm. To provoke DOMS in these muscles, all subjects carried out 4 sets of 25 repetitions of biceps concentration curls while seated on a chair, and the elbows supported on their thighs. Subjects were advised to lower the weight and lift it at a steady rate (approximately 3 seconds going down, and 3 seconds coming back up), to ensure that the eccentric component of the muscle contraction was properly done. There was a 90 second resting period between sets, and subjects either did the full set of 25 repetitions, or were instructed to stop the set if they failed to steadily control the descent of the weight and return their arm back to full flexion. As indicated previously, the resistance used was 35% of each subject's RM.

All the primary measurements were repeated after the exercise at 30 minutes, 24, 48, 72, and 96 hours except for the myoglobin measure which wasn't carried out at 24 hours. Also, the 2nd and 3rd dose of the supplements were taken immediately after the exercise and at 24 hours.

Data Analysis

Means, and standard errors (SEM) were calculated. Measurements of all variables (MS, EMG, RROM,SF-MPQ, Myoglobin, and Skin Temperatures) were compared over time between the experimental and placebo groups of each of the 2 main groups (healthy and diabetic) using a mixed factorial (2 × 6) analysis of variance (ANOVA). When a significant difference over time was found, a paired t-test was performed to determine any significant differences from baseline. Demographic data and the protein intake (from the FFQ analysis) were compared using independent-t tests. Statistical analysis was performed using PASW Statistics Version 18.0.0 (SPSS, Inc., 2009, Chicago, IL, www.spss.com), and the level of significance was set at $\alpha<0.05$.

RESULTS

Demographics and Protein Intake

There were no significant differences in demographic data between the two treatment groups of the healthy subjects group ($P > 0.05$). Also, no significant difference between the baseline protein intakes was observed. The same results were also seen for the diabetic subjects group, where no significant differences were found between the two treatment groups in regards to demographical data, and protein intake ($P > 0.05$).

Muscle Strength (MS)

There was no significant difference in MS between the two treatment groups in the healthy group ($P > 0.1$). However, there was a difference in MS over time, with a significant decrease in MS at day1 ($P < 0.01$), compared to baseline.

In the diabetic group, there was no significant difference in MS between the two treatment groups ($P > 0.1$).However, there was a significant decrease in MS at day1 ($P < 0.05$), compared to baseline. Figure 2 shows the MS response for all 4 groups.

Electromyography (EMG)

There was no significant difference in EMG between the two treatment groups in the healthy group ($P > 0.1$). There was also no significant difference over time ($P > 0.05$).

In the diabetic group however, there was a significant difference in EMG between the two treatment groups ($P < 0.05$), where the placebo group had a significantly lower EMG amplitude during maximum effort when compared to the BCAA group. There was also a difference in EMG over time, with a significant decrease in EMG at day 3, day4, and day5 ($P < 0.05$), compared to base line. Figure 3 illustrates the EMG response during maximum effort for all 4 groups.

Pain/Soreness Response (SF-MPQ)

There was no significant difference in the pain scores from the SF-MPQ among the two treatment groups in the healthy group ($P > 0.1$). Pain scores differed overtime however, where there was a significant increase in pain at day1, day2, day3, and day4 ($P < 0.05$), compared to baseline.

In the diabetic group, there was a significant difference between the two treatment groups in regards to the level of perceived pain ($P < 0.05$), where the placebo group had higher pain than the BCAA group. A difference in pain over time was also found, where there was a significant increase in pain at day2, day3, and day4 ($P < 0.05$), compared to baseline in the placebo group. In the BCAA group however, the only significant time difference from baseline was at day 3 ($P < 0.05$). Figure 4 shows the pain scores from the SF-MPQ for all 4 groups.

Relaxed Range of Motion (RROM)

There was no significant difference in RROM between the two treatment groups in the healthy group ($P > 0.1$). However, there was a difference in RROM over time, with a significant decrease in RROM for all time points (day1, day2, day3, day4, day 5) compared to baseline ($P < 0.05$).

Also in the diabetic group, where there was no significant difference in RROM between the two treatment groups ($P > 0.1$). However, there was a significant decrease in RROM at day1, day2, day3, and day4 ($P < 0.05$), compared to baseline. Figure 5 shows the RROM measurements in all 4 groups.

Myoglobin Concentrations

There was no significant difference in myoglobin concentrations between the two treatment groups in the healthy group ($P > 0.1$). However, there was a difference in myoglobin concentrations over time, with a significant increase in myoglobin concentrations at day3, day4, and day5 ($P < 0.05$) compared to baseline.

In the diabetic group, there was a significant difference in myoglobin concentrations between the two treatment groups ($P < 0.05$), where the placebo group had higher blood myoglobin concentrations than the BCAA group. A difference over time was also found, with a significant increase in myoglobin concentrations at day3, day4, and day5 ($P < 0.05$), compared to baseline in the placebo group. In the BCAA group however, the only significant time difference from baseline was at day 4 ($P < 0.05$). Figure 6 shows the blood myoglobin concentrations for all 4 groups.

Skin Temperatures

There was no significant difference in skin temperatures between the two treatment groups in the healthy group ($P > 0.05$). However, there was a difference over time, with a significant increase in skin temperatures at day1 ($P < 0.05$), compared to baseline for both groups. Skin temperatures in the placebo group were still significantly elevated at day 2 ($P < 0.05$) compared to baseline, whereas in the BCAA group, skin temperatures at day 2 were not significantly different from baseline ($P > 0.05$).

Also in the diabetic group, where there was no significant difference in skin temperatures between the treatment groups ($P > 0.05$). There was however, a time difference, where there was a significant increase in skin temperatures at day1 ($P < 0.05$), compared to baseline for both groups. Also, similar to the diabetics group, skin temperatures for the placebo group were still significantly elevated at day 2 ($P < 0.05$) compared to baseline, whereas for the BCAA group there was no significant difference between day 2 and baseline measures ($P > 0.05$). Figure 7 shows the skin temperature measurements for all 4 groups.

Table 1 Means (+/- SEM) of the general characteristics of the Subjects

Subject Type	Supplement	N	Age (Years)	Height (Cm)	Weight (Kg)	BMI	HbA1c (%)	Diabetes Duration (Years)
Healthy	BCAA	14	28.2 (+/- 2.0)	168.3 (+/- 2.1)	72.9 (+/- 4.7)	25.2 (+/- 1.3)		
Individuals	Placebo	14	28.07 (+/- 2.1)	168.0 (+/- 2.3)	72.7 (+/- 5.0)	25.5 (+/- 1.4)		
Diabetic	BCAA	8	60.6 (+/- 5.7)	166.7 (+/- 5.5)	98.7 (+/- 11.8)	34.8 (+/- 3.0)	7.5 (+/- 0.8)	7.7 (+/- 2.3)
Individuals	Placebo	8	61.9 (+/- 3.3)	168.5 (+/- 4.9)	118.9 (+/- 15.5)	41.3 (+/- 4.2)	6.7 (+/- 0.4)	5.5 (+/- 1.9)

Figure 1 A typical subject setup for the repetition maximum (RM) and muscle strength (MS) measurements while the examiner is giving verbal cues. Also seen here is the strain gauge device with the wrist strap, securely attached to the 45° angled bench.

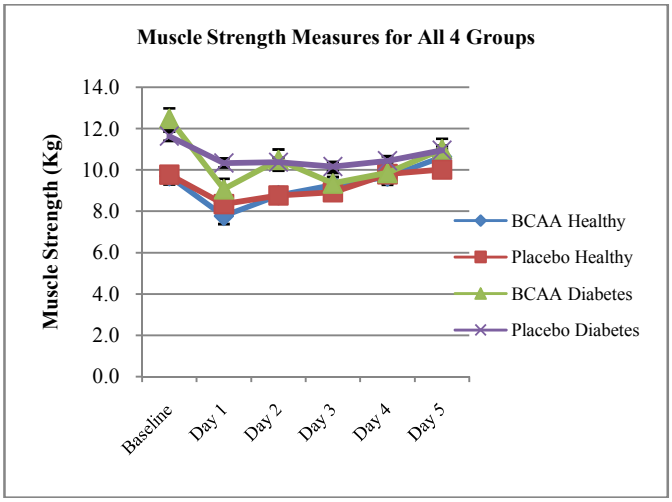

Figure 2 Graph of the muscle strength measures(Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 6 time periods.

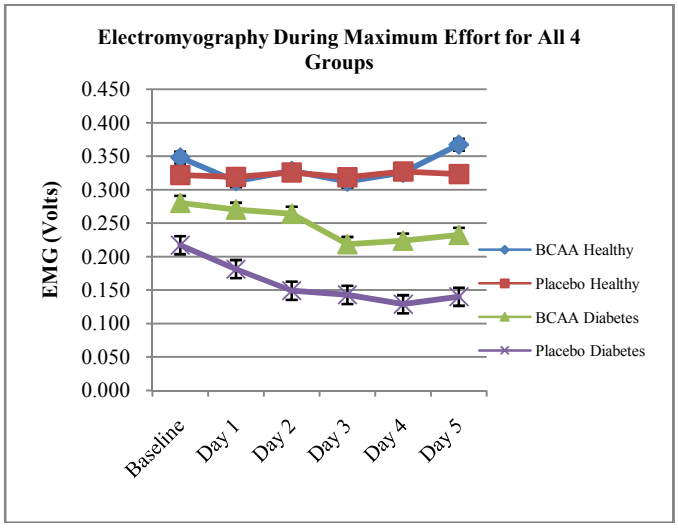

Figure 3 Graph of the electromyography (EMG) amplitude during maximum effort (Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 6 time periods.

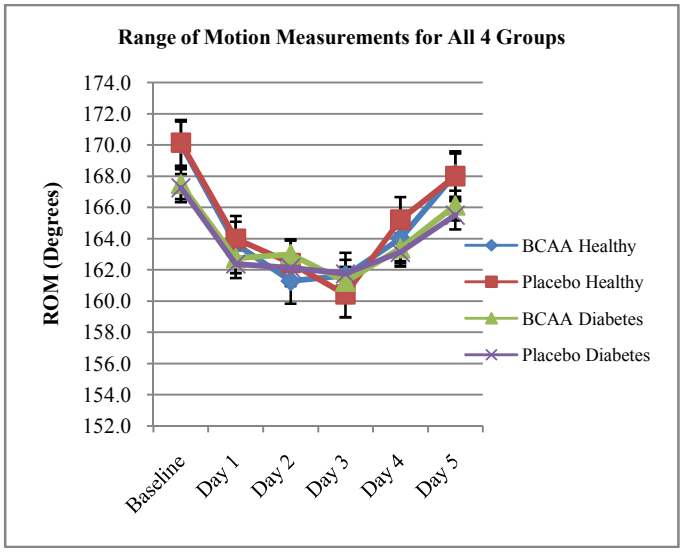

Figure 4 Graph of the relaxed range of motion (RROM) measurements(Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 6 time periods.

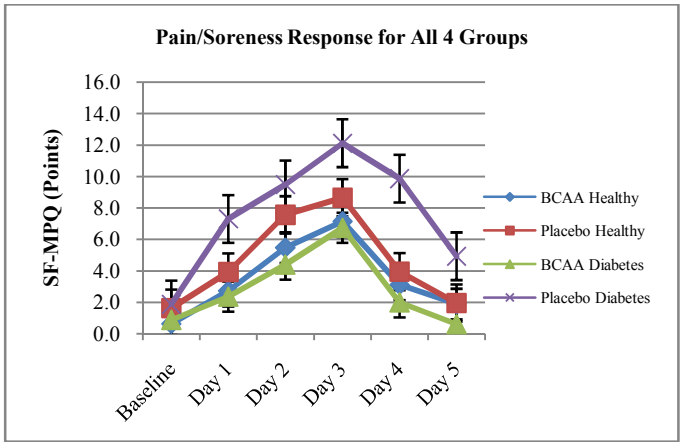

Figure 5 Graph of the soreness responses using the SF-MPQ(Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 6 time periods.

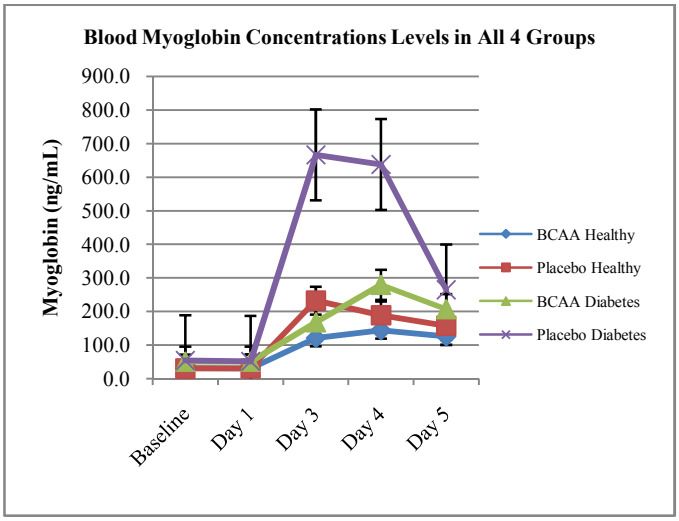

Figure 6 Graph of the blood myoglobin concentrations (Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 5 time periods.

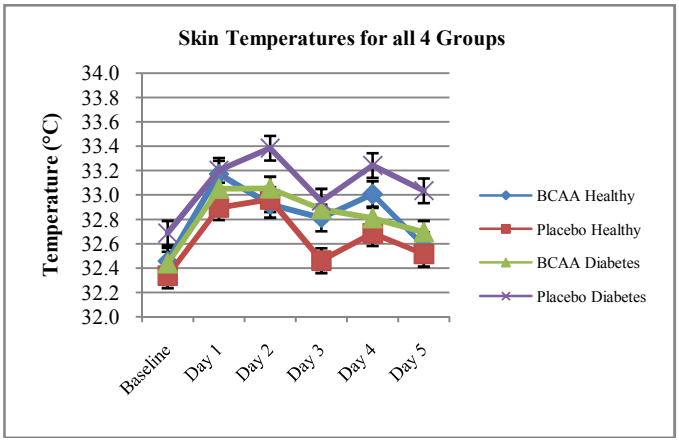

Figure 7 Graph of skin temperatures (Means +/- SEM) in the healthy group who ingested the BCAA supplement (diamonds), the healthy group who ingested the Placebo supplement (squares), the diabetic group who ingested the BCAA supplement (triangles), and the diabetic group who ingested the Placebo supplement(X), over the 6 time periods.

DISCUSSION

Exercise is still considered one of the best means of increasing glycemic control in people with diabetes, particularly resistance exercise [7]. It has been shown that an overall increase in muscle mass is associated with better insulin sensitivity [13,9]. Resistance exercise however, especially the eccentric phase, has been attributable to micro-traumas and damage of protein structures within skeletal muscles [38,20,59]. This damage alters the protein turnover process within the muscle, which causes a decrease in performance and in the body's BCAA content (and some other essential amino acids) during the recovery period after exercise [44,43,42].

There has been a heightened interest lately in nutritional supplementation, in treating DOMS and its associated symptoms. In these studies, BCAA has been found to have promising effects in facilitating the restoration of muscle function, and attenuating muscle damage following exercise [22,45,60,51,52,23]. However, because people with diabetes have endothelial dysfunction, soreness levels are worse after exercise and recovery periods longer [26,28].

No study up to date has investigated BCAA effects on a diabetic population, which was the focus of this study. In this investigation, subjects participated in a moderate intensity resistance exercise to induce DOMS, and identify the effectiveness of BCAA supplementation in enhancing the recovery of DOMS, and its perceived symptoms. This study was also unique in the fact that we used a BCAA dosage dependent on lean body weight, rather than just the individual's weight. The reason for incorporating this method is that diabetic individuals, on average, have higher fat distributions when compared to non-diabetic individuals. Also, because BCAA is mainly metabolized in skeletal muscle, we thought that the incorporation of the individual's whole body weight in the dosage calculation might not be necessary. From this investigation, we found that BCAA supplementation could be a useful method for treating DOMS and facilitating muscle recovery in a diabetic population.

BCAA when consumed before or after an acute exercise session has been found to further stimulate muscle protein synthesis, and reduce muscle protein breakdown, resulting in an enhanced muscle adaptation to the related damage [46,45,47]. These positive results were seen in the diabetic group, where some of the muscle damage markers were decreased when compared to the placebo group.

In regards to the EMG response, the diabetic BCAA group showed a better maintenance of their muscle activity output, while the diabetic placebo group had a larger decrease. This could be attributed to the fact that an increased dose of leucine has been found to help maintain the muscles force output during isometric contractions[22]. Perceived soreness, and myoglobin concentrations in the diabetic BCAA group were much lower than in the diabetic placebo group. This response has been observed in a number of studies that have incorporated the use of BCAA, or leucine supplementation on the markers of muscle damage and DOMS[52,60]. Although skin temperatures were not significantly different between the two diabetic groups, a notable finding was that skin temperatures were closer to baseline in the BCAA group at 24 hours, while temperatures were still elevated in the placebo group at that same time period. This indicates that there were higher blood flows in the exercised muscle of the placebo group, due to increased inflammation and tissue damage [59].

An interesting finding in our study was that the BCAA supplement had enhanced the recovery in the diabetic group, but had almost no effects on the healthy group, even though the dosage duration was short. A critical explanation for this occurrence could be ascribed to the fact that diabetic individuals have a high prevalence of gastrointestinal complications including dyspepsia, and abdominal pain [61,62]. Diabetes mellitus is known to provoke many complications such as retinopathy and nephropathy; gastrointestinal dysfunction is just one of these many complications [61,63]. Neuropathy and hyperglycemia have been found to cause abnormal gastrointestinal motility and disturbed digestion, which together have shown to cause impaired intestinal absorption [64-66]. This may result in the mal-absorption of essential amino acids from the proteins in the diet of a diabetic individual. Thus, an amino acid supplement would be much easier for the diabetic individual to absorb through an impaired gastrointestinal system.

On the other hand, we found no significant differences between the healthy BCAA group, and the healthy placebo group. A main reason for this finding could be related to the fact that the supplementation duration wasn't long enough. Studies have concluded that the duration of BCAA supplementation could have a large impact on its effects on DOMS[67,53]. For example, a study done by Sharp and colleagues [45] found that BCAA supplementation had significant effects on lowering DOMS, but their supplementation period was over the length of 4 weeks (3 weeks before the exercise, and 1 week after).These positive effects were seen even though the exercise routine they incorporated was intense, as it included muscles of the whole body (circuit training) rather than just the arm, or leg muscles. Also, another study done by Skillen and colleagues[68], administered an amino acid supplement over a period of 2 weeks and found that it had beneficial effects on reducing muscle damage markers.

One of the limitations of this study is that we only assessed the subject's dietary intake at baseline, and failed to assess their intake over the course of the study. This obviously limits our ability to detect changes in intake, especially in regards to protein content. Another limitation would be the fact that we didn't incorporate a strict dietary program for the subjects during the time of the study. However, even though this would increase the studies internal validity, it might decrease its external validity. Suggestions for further studies would be to incorporate different vitamins into the BCAA supplement. Vitamin E would be a good example, as it is considered an antioxidant, which has been found to be effective in attenuating exercise induced muscle damage[15,69].

Despite the limitations of this study, we have provided suggestive evidence that BCAA supplementation in a diabetic population can be beneficial in enhancing muscle performance, and improving recovery from DOMS. BCAA supplementation would be a simple method for stabilizing the muscle's protein content after an acute bout of resistance exercise in people with diabetes. This could assist in minimizing further injuries from over-exercising in this population. However, further investigations are required to clarify and elucidate these findings.

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