The Effect of Boron Supplementation on Lean Body Mass, Plasma Testosterone Levels, and Strength in Male Bodybuilders

Arny A. Ferrando and Nancy R. Green

The effect of boron supplementation was investigated in 19 male bodybuilders, ages 20–27 years. Ten were given a 2.5-mg boron supplement while 9 were given a placebo every day for 7 weeks. Plasma total and free testosterone, plasma boron, lean body mass, and strength measurements were determined on Days 1 and 49 of the study. Plasma boron values were significantly (p<0.05) different as the experimental group increased from (±SD) 20.1 ±7.7 ppb pretest to 32.6 ±27.6 ppb posttest, while the control group mean decreased from 15.1 ±14.4 ppb pretest to 6.3 ±5.5 ppb posttest. Analysis of variance indicated no significant effect of boron supplementation on any of the dependent variables. Both groups demonstrated significant increases in total testosterone, lean body mass, 1-RM squat, and 1-RM bench press. The findings suggest that 7 weeks of bodybuilding can increase total testosterone, lean body mass, and strength in lesser trained bodybuilders, and that boron supplementation had no effect on these measures.

Key Words: total testosterone, free testosterone, 1-RM, squat, bench press

Boron essentiality in humans has not been established. Animal studies have linked boron to bone mineralization via its effect on calcium, phosphorus, and magnesium metabolism (9,11). Nielsen et al. (15) investigated the effects of boron on mineral metabolism in 12 postmenopausal women. Boron supplementation of 3 mg/day was found to reduce urinary calcium of subjects consuming a low magnesium diet, and to significantly increase serum estrogen and testosterone.

Athletes involved in weight training for increased strength or muscular size have long sought to enhance their natural testosterone levels. The use of exogenous testosterone, or anabolic steroids, has been the means of choice; however, the dangers and side effects of anabolic steroids are well documented (8). In addition, the felonious nature of their possession has prompted many athletes to seek safer and more natural means of testosterone enhancement. Recently a proliferation of athletic supplements has been marketed, touting boron as an ergogenic aid.
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Capable of increasing testosterone. The efficacy of boron as an ergogenic aid is based exclusively on the increased testosterone values found in the Nielsen et al. study (15) on postmenopausal women.

Manufacturers of athletic supplements often market products as anabolic or ergogenic aids based on incomplete scientific investigation. The effect of boron supplementation demonstrated in a small population of postmenopausal women cannot be extrapolated to a population of young athletes. Therefore the purpose of this study was to examine the effect of a commercially produced boron supplement on plasma free and total testosterone (T), lean body mass (LBM), and strength values in healthy male bodybuilders.

**Methods**

**Subjects and Training**

Nineteen male bodybuilders volunteered to participate in this study. The study was approved by the Florida State University Human Subjects Review Board. All subjects had been weight training for at least 1 year prior to when the study began. The subjects continued to weight train using a bodybuilding protocol at least 4 days a week throughout the 7 weeks of this study. Each subject outlined his training regimen in a prestudy questionnaire and was instructed to not change his regimen during the study. None of the subjects had used anabolic steroids within the 6 months immediately preceding the study.

**Experimental Procedures**

Subjects reported to the laboratory at 8 a.m. and were briefed on study requirements and procedures. Informed consent and medical history were obtained prior to data collection. Subjects were also asked to complete a pretest questionnaire.

A 3-day dietary record was collected over the first and last 3 days of the study to assess nutritional intake. Diets were analyzed for nutrient composition utilizing the Nutritionist III food/nutrient data base. Subjects were instructed to continue their normal dietary habits but to refrain from taking any vitamin, mineral, or athletic supplements (amino acid, elixir formulas, etc.). They were also required to stop ingesting athletic supplements 3 weeks before the study began. Subjects were initially weighed hydrostatically in order to determine lean body mass. Blood was drawn from an antecubital vein for determination of plasma boron (B) and testosterone. Then subjects went to a local gym to have strength values determined.

Following the initial evaluation, subjects were randomly placed in a double blind fashion into one of two groups. The experimental (B) group (n=10) received a commercial B supplement and the control group (n=9) received a placebo (milk protein). Both groups were given the total 49 tablets and instructed to take one tablet a day. Although the label on the B tablets stated that each tablet contained 5 mg of B, analysis revealed they contained 2.5 ±0.15 mg (M ±SD). Personal contact with the subjects was maintained throughout the study to ascertain any possible side effects or perceived benefits of supplementation. Compliance for both groups was assessed by supplement counts at the end of the 7-week study period.
Following the 7-week supplementation period, subjects again reported to the laboratory at 8 a.m. for hydrostatic weighing and blood sampling. Strength determinations were then conducted at a local gym by the investigators. Subjects completed a posttest questionnaire regarding any side effects or perceived benefits of supplementation.

**Lean Body Mass Determination.** Subjects were asked to void bodily waste and then were weighed on a beam scale. Body composition was determined by hydrostatic weighing with residual volume estimated (16). The weighing procedure was repeated six times and the highest value was used to determine the weight of the subject in water. The protocol for determining body density outlined by Sinning (17) was adapted and used. Vital capacity was determined on a Pneumoscan KTC (K.L. Engineering Co., Sylmar, CA). Each subject attempted three vital capacity measurements and the highest value was used to estimate residual volume. Residual volume was estimated according to Wilmore (19).

**Percent body fat and LBM were calculated.**

**Strength Determination.** Strength scores were determined by the one-repetition maximum (1-RM) in the bench press and back squat. To perform the bench press, the subject was required to lower the weight to the chest and return it to the straight arm (starting) position while maintaining the buttocks in contact with the bench and the feet flat on the floor. In the back squat, the subject squatted with the weight on his shoulders until the top of the thigh at the hip joint was parallel with the knee (a parallel squat), then returned to the upright position. Spotters ensured each lifter’s safety.

Subjects began by warming up for two to three sets. The first attempt to determine the 1-RM consisted of a weight that was within 30 lbs (squat) or 15 lbs (bench) of their self-reported 1-RM. Subsequent lifts were increased until the subject either failed to complete the lift or indicated that he had reached a maximum and could lift no more. If the lifter failed to complete a weight within the prescribed parameters, he was allowed to rest and given one more attempt at that weight. The heaviest weight successfully lifted was recorded as the subject’s 1-RM.

**Blood Collection and Analysis.** On Days 1 and 49 of the study, fasted blood was drawn by venipuncture between 8:30 and 9:30 a.m. in consideration of the diurnal variation of plasma T (2). Blood on Day 49 was drawn within 15 minutes of the time it had been drawn on Day 1. Venous blood was collected into 7- and 10-ml nonborosilicate vacutainers (Becton-Dickinson) with multisample disposable needles. Blood was collected into the 7-ml EDTA tubes for plasma analysis of free and total T. Blood was collected into two 10-ml sodium-heparinized tubes for blood B analysis. A total of 25 ml of blood was collected for each subject.

All blood was centrifuged at 3,500 g for 15 minutes in a Fisher Centrifuge Model 225. Plasma utilized for T analysis was pipetted into 13 x 100 mm culture tubes (Fisher Scientific), capped, and frozen at –50°C. Plasma for B analysis was pipetted into acid-washed (HNO₃) 17 x 100 mm polypropylene (Becton-Dickinson) tubes, capped, and frozen at –50°C.

Free and total T were determined by RIA Coat-A-Count methods (Diagnostic Products Corp., Los Angeles). Prior to assay, samples were allowed to thaw at room temperature and then were mixed by gentle swirling. Each sample was analyzed in duplicate. All subjects fell within total T normal range (2.70–10.70...
ng/ml) and assay parameters (0.2–16.0 ng/ml). Free T was assayed over the range of 0.5–50.0 pg/ml (determined by human serum based calibrators). All subject samples were analyzed in one respective assay. Average intra-assay coefficients of variation were 2.90% and 2.98% for total T and free T, respectively.

A microwave digestion technique was developed for sample digestion prior to plasma B analysis (3). Inductively coupled argon plasma spectroscopy (ICAP) was used to determine B concentration (10). Instrumentation settings and analytical procedures are enumerated elsewhere (3).

**Supplement and Standard Analysis.** All boron and placebo tablets were from the same respective manufactured lot. B tablets and placebo supplements were analyzed according to the procedures in Ferrando (3).

National Bureau of Standards (NBS) standard reference material (SRM) 1572 (citrus leaves) and NBS SRM 1567a (wheat flour) were used as standards. Although the NBS has not certified the level of B in these standards, analysis was performed as a comparison to values obtained by Hunt et al. (10), who used an open vessel, wet digestion technique. Wheat flour was selected as a second control because it contains a lower B level that is closer to blood values. Analysis procedures for SRM citrus leaves and wheat flour are reported by Ferrando (3).

All analyses were conducted with matrix (12% HNO₃) spikes as control values. Matrix spikes of 1.0 ppm B were analyzed with the citrus leaves and wheat flour standards. In the analysis of plasma B, known blood was spiked with 0.5 ppm B. A blank of known blood was also digested and run with each analysis.

**Statistical Analysis.** The Biomedical Data Package (BMDP) computer statistical program was used for data analysis. Descriptive statistics were performed for all variables. A 2 x 2 (B/Placebo x Pre/Posttreatment) analysis of variance was used to test the dependent variables. All variables were tested for homogeneity of variance. When significant F ratios were obtained, the Fisher least significant differences (LSD) post hoc procedure was employed to locate significant differences between the means. All hypotheses were tested for significance at the p≤0.05 level.

**Results**

**Supplements and Standards**

Ten B tablets were analyzed on five occasions and six placebo tablets were analyzed on three occasions for B content. The B supplement contained 2.49 ±0.12 mg of B and the placebo contained 0.002 ±0.001 mg.

SRM 1572, citrus leaves, was analyzed through four samples on two occasions. Values ranged from 49.3 to 54.9 ppm, with a mean of 51.76 ±2.53 ppm. Analysis of four samples of SRM 1576a, wheat flour, resulted in a range of 0.312 to 0.554 ppm, with a mean of 0.452 ±0.10 ppm.

**Subjects**

Group means of subjects’ age, height, weight, and training experience are listed with dietary data in Table 1. There was a significant difference in training history (p<0.05). The experimental group had been weight training for 7.3 ±4.7 years while the control group had had 4.1 ±2.1 years of weight training experience.
### Table 1

**Summary of Subject Group Anthropometric and Dietary Data**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental (n=10)</th>
<th>Control (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>23.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Training (yrs)</td>
<td>7.3</td>
<td>4.7a</td>
</tr>
<tr>
<td>Kcal/day</td>
<td>3556</td>
<td>2013a</td>
</tr>
<tr>
<td>%CHO</td>
<td>59.8</td>
<td>14.6a</td>
</tr>
<tr>
<td>%Protein</td>
<td>18.3</td>
<td>7.5</td>
</tr>
<tr>
<td>%Fat</td>
<td>19.8</td>
<td>8.6</td>
</tr>
</tbody>
</table>

*a*Significant difference between groups, *p*<.05; 
*b*Average of Days 1–3 of study period. Dietary values from Days 47–49 did not differ significantly.

### Table 2

**Summary of Dependent Variable Changes**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boron (n=10)</th>
<th>Control (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>SD</td>
</tr>
<tr>
<td>Leanbody mass (kg)</td>
<td>70.2</td>
<td>7.9</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>8.8</td>
<td>8.3</td>
</tr>
<tr>
<td>1-RM squat (kg)a</td>
<td>151.2</td>
<td>32.5</td>
</tr>
<tr>
<td>1-RM bench press (kg)b</td>
<td>128.6</td>
<td>22.4</td>
</tr>
<tr>
<td>Total testos. (ng/ml)</td>
<td>5.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Free testos. (pg/ml)c</td>
<td>17.3</td>
<td>8.5</td>
</tr>
<tr>
<td>Plasma boron (ppb)</td>
<td>20.1</td>
<td>9.6</td>
</tr>
</tbody>
</table>

*a*Boron n=9, Control n=6; 
b*Boron n=9; 
c*Boron n=9.

*P*<0.01 vs. Pre; **P*<0.001 vs. Pre.

Analysis of 3-day dietary records revealed that individual dietary habits and group means did not deviate significantly from pretest to posttest. However, total Kcal and carbohydrate intakes were significantly (*p*<0.05) different between groups (*t* test), with the control group consuming more total calories (3,804 ±1,063 Kcal vs. 3,556 ±2,013 Kcal) but less carbohydrate (48.5 ±9.8% vs. 59.8 ±14.6%) than the experimental group.

Changes in the dependent variables are consolidated in Table 2. The experimental group increased their mean LBM from 70.2 ±7.9 kg pretest to 71.2...
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ANOVA revealed a significant increase (p<0.01) in LBM for all subjects as a result of 7 weeks of weight training; however, there was no significant difference due to treatment. Body fat percentages decreased slightly from 8.82 ±1.8% pretest to 8.34 ±1.5% posttest, and from 11.70 ±2.2% pretest to 10.82 ±3.0% posttest for the experimental and control groups, respectively. While both groups had a decrease in percent body fat, the decrease was not statistically significant.

Due to injuries, not all subjects were able to perform posttest 1-RMs. However, injuries were limited to specific sites (shoulder, hip, ankle) and did not prohibit subjects from continued training or completing the study protocol. Strength values reported are for subjects who completed both the pretest and posttest squat or bench press. In the squat, the experimental mean (n=9) increased from 151.2 ±32.5 kg pretest to 159.6 ±31.4 kg posttest, while the control group (n=6) increased from 136.5 ±36.8 kg pretest to 146.6 ±15.0 kg posttest. This increase was significant (p<0.001) in both groups and therefore was probably the result of 7 weeks of training (ANOVA). For the bench press, the experimental group mean (n=9) increased from 128.6 ±22.4 kg pretest to 130.5 ±22.9 kg posttest in the bench press, while the control group (n=9) increased from 108.6 ±24.7 kg pretest to 114.1 ±23.7 kg posttest. This increase was again significant (p<0.01) in both groups as a result of 7 weeks of training (ANOVA). There were no statistical differences in 1-RM for the squat or the bench press between groups as a result of supplementation.

Total T values for all subject values were within the normal range of 2.7 to 10.7 ng/ml. The experimental group mean total T increased from 5.36 ±1.6 ng/ml pretest to 7.17 ±2.7 ng/ml posttest; the control mean increased from 5.40 ±2.1 ng/ml pretest to 6.48 ±1.9 ng/ml posttest. Total plasma T did not differ significantly between groups as a result of supplementation (ANOVA), but it did increase significantly in both groups with 7 weeks of training (p<0.01).

Free T values ranged from 5.44 to 34.67 pg/ml, which were within the most reliable portions of the calibration curve. Plasma free T means ranged from 17.25 ±8.5 pg/ml pretest to 19.86 ±6.6 pg/ml posttest for the experimental group (n=9), and from 19.49 ±7.3 pg/ml pretest to 20.86 ±7.2 pg/ml posttest for the control group. One value was discarded in the experimental group due to an inaccurate assay value. Plasma free T did not differ significantly between groups or as a result of training over time (ANOVA). A 2 × 2 correlation matrix between percent change of each plasma T value and percent change of each strength value revealed no significant relationships.

Pretest B values of 20.1 ±7.6 ppb for the experimental group and 15.1 ±14.4 ppb for the control group were not significantly different (t-test; Table 3). The experimental group demonstrated a >90% compliance in their supplementation as determined by supplement collection on Day 49 of the study. The mean plasma level of the experimental group increased from 20.1 ±7.6 ppb pretest to 32.6 ±27.6 ppb posttest, while the control group mean decreased from 15.1 ±14.4 ppb pretest to 6.3 ±5.5 ppb posttest. Plasma B values were significantly different between the groups (p<0.01). Despite the opposite changes in plasma B values, there was no statistically significant interaction of time and B (ANOVA). Post hoc analysis (Fisher LSD) revealed no significant difference as a result of treatment, possibly due to the large standard deviation (±27.6 ppb) of the posttest experimental cell mean.
Table 3

Individual Data for Plasma Boron (ppb)

<table>
<thead>
<tr>
<th>Boron (n=10)</th>
<th>Control (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>24</td>
<td>56</td>
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<td>29</td>
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<td>28</td>
<td>24</td>
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<td>19</td>
<td>23</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>22</td>
<td>75</td>
</tr>
</tbody>
</table>

Mean^b 20.1 32.6 15.1 6.3
SD 7.7 27.6 14.4 5.5
SE 2 9 5 2

^aDetection limit was 12 ppb; calculated values ±12 ppb are reported as descriptive statistics only. ^bThree replicates for each sample were averaged; negative values were averaged with remaining values as zero.

Discussion

When examining changes in strength values, the initial training status of the subjects must be taken into account. Häkkinen and Komi (4) demonstrated that novice weight trainers can achieve approximately twice the strength improvement in half the time when compared with initially stronger experienced lifters. Häkkinen et al. (5) found that 21 males described as “accustomed to strength training in a noncompetitive manner for their own conditioning purposes” (p. 287) demonstrated a significant increase in strength after a 24-week progressive resistance program. The majority of this increase was realized in the first 8 weeks of the program.

Subjects in this study were lesser trained and similar to those characterized by Häkkinen et al. (5). All subjects followed a bodybuilding training regimen—a weight training regimen that includes components for both muscular strength and endurance with the intent to develop overall body symmetry and muscular size. Subject training protocol and training volume was neither controlled nor recorded; however, subjects were asked not to change their training regimen. It is possible that informal competition between subjects motivated some to increase the relative intensity (% 1-RM) or the volume of training.

The increase of approximately 1 kg of LBM through 7 weeks of weight training found in the present study is consistent with the literature. A review of the literature regarding physiological adaptations to resistance training (12, 13) noted that strength training will typically increase LBM. A 1-kg increase in LBM
was noted after 5 weeks (18) and 10 weeks (20) of weight/strength training in 8 and 26 males, respectively. In addition, it is possible that subjects could have altered their diet in the middle 5 to 6 weeks of the study that were not described by the dietary recall. Dietary changes may have affected LBM changes.

The absence of change in free T is in agreement with the literature (1, 7). However, research indicates that there is no change in total T during training programs of 1 week (7), 24 weeks (1, 5), or 1 year (6). Closer examination reveals T increases during shorter subperiods of training. Hākkinen et al. (5) subjected a group of 11 males of similar training status to subjects in the present study to a 24-week strength training program. A significant increase \((p<0.05)\) in serum total T was noted in these subjects after 8 weeks of training. Because the increase in plasma T was evident in both groups in this study, it cannot be attributed to B supplementation. The subjects displayed a high level of training activity; therefore the T increase was probably the result of bodybuilding training.

Despite the overall increases in both group means of total T and strength parameters as a result of training, there was no correlation between the increase in muscle strength and plasma T values. The absence of correlation between the percent changes in total T and strength values in the present study is consistent with the literature (1, 6). Alén et al. (1) noted a significant \((p<0.01)\) correlation between percent change in free T and percent change in strength during the last 4 weeks of a 24-week strength training period. However, no such correlation was noted in the present study. Therefore the increase in strength parameters was most likely the result of a concentrated bodybuilding training program.

It is highly probable that B supplementation increases plasma B levels. A \(t\) test of pre- and posttest values of each group revealed that plasma B levels in the experimental group increased significantly while the control group values decreased significantly \((p<0.05)\). The ANOVA approached significance \((p<0.07)\) due to B supplementation, despite a large standard deviation (±27.6 ppb) in the posttest experimental group values. There were no significant correlations between plasma B and any of the dependent variables. Furthermore, there was no consistent trend between changes in plasma B and changes in T or strength values. For example, certain subjects with a significant increase in plasma B demonstrated marginal increases in total T and strength, whereas others with a significant decrease in plasma B demonstrated moderate increases in total T and strength.

There was a wide variation in plasma B values in the experimental group (≤2 to 77 ppb). Five subjects responded to B supplementation while two demonstrated no response and two demonstrated a decrease in plasma levels (Table 3). Plasma B values may have fluctuated due to the timing of supplement ingestion prior to blood sampling. Subjects were instructed to take one (2.5 mg) tablet per day but were not instructed to do so at a specific time of the day. The last tablet was to be taken the day before the early morning posttest session. Therefore supplements may have been taken between 8 and 24 hours prior to blood sampling. Daily B excretion rates have not been determined; however, it is possible that this relatively small intake would be rapidly metabolized and excreted from the body. Although physical observation of supplement ingestion was not possible, compliance as assessed by returned supplements was >90% in the experimental group. Since the experimental group displayed a significant increase in plasma
B, it can be concluded that 7 weeks of supplementation is capable of elevating plasma levels.

It is noteworthy that eight of the control group’s plasma B values were at or below the detection limit while only five of the pretest values were below detection limits. The decline in posttest control values may be the result of one or more factors. ICAP analysis near the detection limit often results in negative values. Each plasma sample was evaluated by three separate readings and a negative value was averaged with the remaining values as a zero (Table 3).

Another factor affecting plasma B may have been a fluctuation in B intake. A national database for B levels in foods and personal care products has not been established; therefore it is not possible to quantify B intake. Also, plasma B may have declined due to training. Although subjects were asked not to change their training regimen for this study, it is not certain whether the noted increased training activity contributed to the decrease in posttest plasma B values. Though not used in the present study, a crossover design would have further defined the effect of training on plasma B.

The proposed efficacy of B as an ergogenic aid is based on its ability to increase T. Nielsen et al. (15) proposed that the increase in serum T and \( \beta \)-estradiol demonstrated in 12 postmenopausal women was the result of an endocrine mechanism. However, the inability of B supplementation to increase plasma T in the present study may indicate that the affected endocrine site and the resulting T production, if it occurs in young males, is not significant.

Nielsen et al. (15) did not measure plasma B levels in their subjects; however, their subjects were on a basal diet containing only 0.25 mg B/day, which was then supplemented with 3 mg B/day. Based on Nielsen’s average intake of 0.5 mg B/day (14) for a mixed diet, the subjects in the present study had comparable levels of B consumption, \( \approx3.0 \) mg B/day in the present study versus \( \approx3.25 \) mg B/day in the Nielsen et al. study (15). Thus it appears that the affected mechanism demonstrated in Nielsen et al. (15) is not applicable or significant in a male bodybuilding population.

References


6. Häkkinen, K., A. Pakarinen, M. Alén, H. Kauhanen, and P.V. Komi. Relationships


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