Acute response of plasma markers of bone turnover to a single bout of resistance training or plyometrics

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Rogers RS, Dawson AW, Wang Z, Thyfault JP, Hinton PS. Acute response of plasma markers of bone turnover to a single bout of resistance training (RT) or plyometrics (PLY). J Appl Physiol 111: 1353–1360, 2011. First published August 25, 2011; doi:10.1152/japplphysiol.00333.2011.—The time course of changes in plasma bone turnover markers following an acute bout of resistance training (RT) or plyometrics (PLY) has not been well characterized. This study is the first to compare the acute response of bone formation and resorption markers to a single bout of RT or PLY. Using a partially randomized, cross-over study design, 12 recreationally active men, aged 43 ± 5 yr, each completed four exercise trials: RT (Fed/Fasted) and PLY (Fed/Fasted). In addition to the RT and PLY trials, 5 of the original 12 participants also completed a fasted, no-exercise control trial to examine time-of-day variation. For each trial, blood was drawn immediately before exercise (PRE), immediately following exercise, and 15 min, 30 min, 1 h, 2 h, and 24 h following PRE for determination of plasma bone-specific alkaline phosphatase (BAP), osteocalcin (OC), tartrate-resistant acid phosphatase 5b (TRAP5b), COOH-terminal telopeptide of type I collagen (CTX), testosterone, parathyroid hormone, and cortisol. A one-factor repeated-measures ANOVA was performed for each trial to detect changes in bone markers during the 2 h following RT or PLY. TRAP5b transiently decreased during the 2 h following all exercise trials (main effect for time, P < 0.05), but returned to PRE concentrations 2 h postexercise. BAP, CTX, and OC remained unchanged, except for reductions in BAP and CTX following PLY-Fasted and PLY-Fed, respectively. During the control trial, BAP decreased, while TRAP5b, CTX, and OC remained unchanged. In general, plasma hormone concentrations decreased during the 2 h following PLY or RT, and cumulative decreases in TRAP5b during the 2 h following exercise were positively correlated with cumulative decreases in parathyroid hormone. The results of the present study suggest that the timing of the measurement of bone turnover markers relative to the last exercise bout is important for detection of exercise-associated changes in bone turnover markers, as the markers returned to preexercise values within 2 h of RT or PLY.

bone turnover markers; bone formation; bone resorption; bone-specific alkaline phosphatase; tartrate-resistant acid phosphatase 5b

WEIGHT-BEARING EXERCISE and resistance training (RT) are recommended for the maintenance of bone mass throughout adulthood (28). Mechanical loading that is dynamic, of short duration, and greater in magnitude than habitually experienced by the skeleton induces maximal increases in bone mass and strength (44). Both gravitational loading and muscle contraction forces are important determinants of the skeletal response to mechanical loading, and, because these two forces are highly related in vivo, it is difficult to determine their relative osteogenic effects (24, 27, 32). Structured jump training, i.e., plyometrics (PLY), has the potential to be more osteogenic than RT because, in addition to muscle contraction forces exerted on the skeleton, it is dynamic, involves multiplanar movement, and induces ground reaction forces that are fourfold greater than body weight (48). Ground reaction forces during RT are not significantly greater than body weight (18, 48).

Exercise presumably increases bone mass by altering the balance between bone formation and resorption, such that there is a net gain. However, exercise interventions that increase bone mass do not always result in detectable changes in serum bone formation or resorption markers from pre- to postintervention (38, 45). The standard protocol for determination of serum bone turnover markers is to measure markers after an overnight fast and after 24 to 48 h of no exercise to reduce intraindividual, interindividual, and biological variability (6, 39). Thus it is possible that the protocol for determination of serum bone turnover marker concentration precludes detection of an exercise effect.

Exercise has direct osteogenic effects that are mediated via mechanotransduction of the strains exerted on osteoblasts and osteocytes (43). In addition, exercise has indirect effects on bone, which are associated with the endocrine action of hormones that both respond acutely to exercise and affect bone metabolism. In particular, testosterone (TEST), cortisol (COR) and parathyroid hormone (PTH) all influence bone metabolism (7, 8, 47) and respond acutely to exercise (4, 12, 29, 35).

Furthermore, energy status may also influence bone formation and resorption, including the response of bone formation and resorption to exercise. Short-term fasting (i.e., overnight fasting) has been reported to reduce the diurnal variation of bone resorption markers [serum COOH-terminal telopeptide of type I collagen (CTX)] (10, 20), but not to alter the diurnal variation of bone resorption markers [serum bone-specific alkaline phosphatase (BAP), or osteocalcin (OC)] (11, 20). Longer periods of fasting (i.e., for a period of 4 days) (17) or reduced energy availability (i.e., for a period of 3 days) (21) suppress serum concentrations of bone formation markers (i.e., plasma OC). In addition, reduced energy intake impairs the increase in bone formation that occurs following high-intensity and high-impact aerobic exercise (51). Thus it is important to account for energy status when examining the response of bone turnover markers to exercise.

To the best of our knowledge, no previous studies have compared the acute response of bone turnover markers to RT vs. the response to PLY, while controlling for energy status. Therefore, the overall objective of the present project, which included two studies, was to examine the acute response of bone turnover markers to a single-bout of RT or PLY.

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Study 1

The primary purpose of study 1 was to describe the acute response of a plasma marker of bone formation (BAP) and of resorption [tartrate-resistant acid phosphatase 5b (TRAP5b)] to a single bout of RT or PLY in the fed or fasted state. We hypothesized that, compared with RT, PLY would induce a greater increase in BAP and a greater reduction in TRAP5b, and that this response would be suppressed by fasting. A secondary purpose of study 1 was to determine whether the acute changes in the bone turnover markers may be associated with changes in hormones that both respond to exercise and influence bone remodeling (i.e., TEST, COR, and PTH). We hypothesized that the effects of exercise on bone turnover markers, regardless of exercise mode or feeding status, would be associated with exercise-induced changes in TEST, COR, or PTH.

Materials and Methods

Study 1

Experimental design. A repeated-measures, cross-over design, randomized by exercise mode, was used to test our study 1 hypotheses that a single bout of RT or PLY would increase plasma concentrations of BAP and decrease plasma concentration of TRAP5b, and that fasting would suppress these effects compared with feeding. Each participant performed four exercise trials separated by a minimum of 3 min rest periods. Following all RT sessions, subjects consumed the same meal of his or her choosing the evening before each trial, and the same meal of his or her choosing the evening following each trial.

Study participants. Twelve physically active men (≥5 h/wk of aerobic exercise), aged 43 ± 5 yr (24–62 yr), participated in study 1. Exclusion criteria included regular participation in RT or PLY, current or previous medical condition affecting bone health, current use of medications that affect bone health, implanted metal that would interfere with determination of bone mineral density (BMD), recent fracture, cigarette smoking, excessive alcohol consumption (>3 drinks/day), irregular sleep-wake cycle, or osteoporosis, as defined by the World Health Organization (25). Before participation, all participants were informed of the risks associated with the study, read a consent form, and provided written consent. The present study was conducted in accordance with the guidelines of the Declaracion of Helsinki and was approved by the University of Missouri Health Sciences’ Institutional Review Board.

Training and diet records. Current physical activity was quantified using a 7-day written training log in which participants recorded activity type, duration, and intensity. The Compendium of Physical Activities was used to estimate daily energy expenditure during purposeful exercise only (2). Nutrient intake was assessed using a 7-day written diet record, which was analyzed for energy, macronutrient, and micronutrient content (Food Processor 10.2; ESHA, Salem, OR). Use of vitamin and mineral supplements was assessed via the screening questionnaire. One of the 12 subjects reported consuming a dietary supplement containing calcium (not included in nutrient analysis).

Bone mineral content, density, and body composition testing. Bone mineral content (BMC) and areal BMD were measured by dual-energy X-ray absorptiometry (Hologic QDR 4500A, Waltham, MA) scans of the whole body, lumbar spine (L1–L4), and total left hip. The whole body scan was also used to determine body composition. Areal BMD (g/cm²) was calculated by dividing BMC (g) by bone area (cm²) by the software associated with the dual-energy X-ray absorptiometry scanner (Hologic QDR 4500A). The coefficients of variation (CVs) for BMC and BMD of the lumbar spine and hip were <1%.

Baseline exercise familiarization and testing. Before participation in the exercise trials, subjects reported to the human exercise physiology laboratory for familiarization with the RT and PLY protocols. Participants underwent one-repetition maximum (1-RM) testing for squat, military press, dead lift, and bent-over row, as well as 10-repetition maximum (10-RM) testing for the lunge and calf raise. All RT exercises were performed using free weights. Study personnel supervised familiarization, repetition maximum testing, and exercise trials.

Exercise trials. The Fasted trials were performed before the Fed trials, and each subject was randomized to the order of either RT-Fasted or PLY-Fasted. Following the Fasted trials, the Fed trials were completed in the same order as the Fasted trials. All trials began between 6:00 and 7:00 AM, and each participant began each trial at the same time of day. All trials were separated by a minimum of 7 days.

Each PLY session was performed in the following order: squat jump, forward hop, split-squat jump, lateral box push-off, bounding, lateral bounding, box drill, lateral hurdle, depth jump (10 cm), and a jump off a box (10 cm). The majority of jumps were performed as 1 set of 10 repetitions, utilizing 10-s rest periods between repetitions and 2-min rest periods between exercises. Bounding-type jumps (i.e., bounding, lateral bounding, box drill, and zig-zag) were performed as 2 sets of 5 repetitions continuously, followed by a 30-s rest period between series of repetitions and 2-min rest period between exercises. The rest between jumps was included because insertion of rest periods between loading cycles enhances the osteogenic effect in animal studies (33, 34, 40).

Each RT session consisted of 3 sets of 10 repetitions of 6 exercises that were selected because they load the hip and spine: squat, military press, dead lift, bent over-row, lunge, and calf raise. The first set was performed at 60% of 1 RM (or 10 RM). The second and third sets were performed at 80% of 1 RM (or 10 RM). All sets and exercises were separated by 3-min rest periods. Following all RT sessions, subjects completed 10 repetitions of abdominal crunches and low back extensions.

Fasting and feeding before exercise trials. Each participant consumed the same meal of his choosing the evening before each trial, and the same meal of his choosing the evening following each trial. The participants were instructed to repeat these meals before and after...
each trial. Before each trial and during the 2 h after each trial, participants were instructed to consume only water ad libitum and were instructed to avoid caffeinated beverages. For the Fasted trials (RT-Fasted and PLY-Fasted), subjects fasted for 10 h until completion of blood collection 2 h following RT or PLY. For the Fed exercise trials (RT-Fed and PLY-Fed), subjects consumed a liquid meal replacement 2 h before exercise (i.e., between 4:00 and 5:00 AM). The same liquid meal replacement was consumed 2 h before the 24-h blood draw during the Fed exercise trials only. Dietary intake was not monitored throughout the study, with the exception of consumption of the liquid meal replacement before Fed trials and repetition of evening meals before and after each trial. The nutrient composition of the liquid meal replacement was as follows: 500 kcal, 12 g fat, 80 g carbohydrate, 18 g protein, 500 mg of calcium, and 6 µg of vitamin D (Wal-Mart Stores, Bentonville, AR).

Blood draws, hormones, and bone turnover marker assays. Before each exercise trial (PRE), a baseline blood sample was drawn in the morning between 6:00 and 7:00 AM, via the antecubital vein by a trained phlebotomist. Blood was also collected immediately following exercise (POST); 15 min, 30 min, 1 h, and 2 h following exercise; as well as at 24 h following the PRE blood sample. Immediately following blood collection, hematocrit was measured using the microhematocrit method (41), and the remaining blood sample was dispensed into plasma-separator tubes containing EDTA. The blood was centrifuged with the use of a tabletop centrifuge (Hettich Zentrifugen, Tuttlingen, Germany) at 500 g for 10 min (2200 × g). The plasma was removed and immediately frozen at −80°C. Changes in plasma volume (∆PV) from PRE values were estimated using the following formula:

\[
\% \Delta PV = \left( \frac{100}{100 - Hct1} \right) \times \left\{ \frac{100(Hct1 - Hct2)}{Hct2} \right\} \% \quad (46)
\]

where Hct1 is hematocrit before RT or PLY, and Hct2 is hematocrit at subsequent time points.

Changes in plasma volume following RT or PLY were minimal (mean change = 1.3 ± 1.4%); therefore, concentrations of analytes were not adjusted for changes in plasma volume. BAP and TRAP5b were measured by ELISA (Quidel, San Diego, CA). All intra-assay CVs were <12%. The interassay CVs for BAP were between 3.9 and 5.8%. The interassay CVs for TRAP5b were between 2.0 and 3.0%. The minimum detection limits for BAP and TRAP5b were 0.7 and 0.2 µU/L, respectively. The concentrations of total TEST, intact PTH, and COR were determined using commercially available chemiluminescent immunoassays (Immulite 1000; Diagnostic Products, Los Angeles, CA). The interassay CVs for COR, PTH, and TEST were <10%. The minimum detection limits for COR, PTH, and TEST were 5 µg/dl, 10 pg/ml, and 10 ng/dl, respectively.

The AUC was determined for each of the bone turnover markers and hormones to quantify the cumulative response of the bone turnover markers and hormones during the 2 h following each trial. Tai’s model (42) was used to determine the AUC, where the change in concentration from POST was determined (on the y-axis) and divided into segments of the different time points assessed (on the x-axis).

Statistical analyses. Descriptive statistics (means ± SE) were calculated for anthropometric measurements, nutrient intake, and physical activity. Bone turnover and hormone data were not normally distributed; therefore, a log-transformation was performed to meet the assumption of normally distributed data required for ANOVA. For ease of interpretation, untransformed data are displayed in Tables 1–5. To determine whether the plasma bone turnover markers were altered during the 2 h following each trial, i.e., to test the hypothesis that a single session of RT or PLY affects plasma concentration of bone turnover markers, we performed a repeated-measures ANOVA on each trial. We tested for a significant main effect for time followed by post hoc pairwise comparisons using the least significant differences when there was a significant time effect. To test for significant differences between PRE and 24 h, a two-tailed, paired t-test was performed for each trial.

To test for main and interactive effects of exercise modes (i.e., RT vs. PLY) and energy status (i.e., Fed vs. Fasted), we used the AUC during the 2 h postexercise as the outcome variable in a two-factor ANOVA. To test the hypothesis that changes in bone turnover markers would be associated with changes in hormone concentrations, we used Pearson’s correlations between the AUCs for BAP, TRAP5b, COR, PTH, and TEST. All statistical analyses were performed using SPSS, version 16.0. Statistical significance was established at an α-level of 0.05 for all analyses.

Study 2

Experimental design. In study 1, we observed a transient decrease in TRAP5b during the 2 h following a single bout of RT or PLY, while BAP remained unchanged (see Table 2). To verify that these results were due to exercise and not to time-of-day variation in the markers of bone turnover (10, 16, 23, 50), we conducted a follow-up study, study 2, which included a fasted, no-exercise CON trial. The subjects were fasted to detect time-of-day variation in the bone turnover markers not associated with feeding. An additional purpose of study 2 was to measure the acute response of a second marker of bone formation (OC) and a second marker of bone resorption (CTX) to a single-bout of RT or PLY. Although both BAP and OC are osteoblast-specific proteins that are used as markers of bone formation (6), they are secreted during different phases of osteoblast development (5). BAP is expressed by newly differentiated osteoblasts, whereas OC is secreted by mature osteoblasts (5). During bone resorption, fragments of collagen with attached cross-links called telopeptides are released into the circulation, one of which is CTX (6, 39). TRAP5b is secreted by the osteoclasts and is a marker of osteoclast number (19) and osteoclast activity (22).

Based on the results of study 1, we determined that energy status had no effect on the acute bone turnover marker response to RT or PLY (see Table 2); therefore, to minimize participant discomfort, we chose to include Fed exercise trials in study 2 for comparison to the no-exercise CON trial. Thus study 2 included a fasted, no-exercise CON trial and RT-Fed and PLY-Fed trials.

Study participants. Five of the 12 participants who completed study 1 also completed study 2. The mean age, height, and weight of these participants was 32 ± 7 yr (24–61 yr), 180.6 ± 19.1 cm, and 83.1 ± 5.2 kg, respectively.

Exercise and CON trials. For the CON trial, subjects remained fasted for 10 h following the evening meal before the trial and until after the completion of blood collection 2 h after exercise. During the time frame exercise would have been performed, i.e., beginning between 6:00 and 7:00 AM, participants remained at rest in a chair in the human exercise physiology laboratory.

Blood draws and bone turnover marker assays. For study 2, blood was collected PRE, POST, 1 h and 2 h following exercise or CON, as well as 24 h following the PRE blood sample. In study 1, the response of the bone turnover markers to RT or PLY was greatest at these time points relative to PRE (see Table 2); thus the 15- and 30-min time points were eliminated in study 2. BAP, TRAP5b, and OC were measured by ELISA (Quidel, San Diego, CA), as was CTX (Immuno-Diagnostic Systems, Phoenix, AZ). The minimum detection limit for OC was 0.45 ng/ml. All interassay CVs were <12%. Intra-assay CVs for OC were between 4.8 and 9.8% and were between 4.7 and 8.8% for CTX.

Statistical analyses. Bone turnover marker data were not normally distributed; therefore, a log-transformation was performed to meet the assumption of normally distributed data required for ANOVA. For ease of interpretation, untransformed data are displayed in Tables 1–5. A repeated-measures ANOVA (n = 5) was performed for each trial to determine the main effect of time for each trial (i.e., RT-Fed, PLY-Fed, and CON). Post hoc pairwise comparisons using the least significant differences were performed when there was a significant main effect for time. To determine differences between PRE and 24 h,
Determined by a two-tailed, paired *P* test. Significantly different than PRE (Table 2). Two hours following RT or PLY, plasma BAP and TRAP5b concentrations were not different than PRE; moreover, BAP and TRAP5b at 24 h were not significantly different than before exercise following any trial (Table 2). To test for main and interaction effects of exercise mode (i.e., RT vs. PLY) and feeding status (i.e., Fed vs. Fasted) on bone turnover markers, a 2 × 2 ANOVA was performed using the AUC for BAP and TRAP5b as the dependent variables. There were no main effects or interactions of exercise mode or feeding status for BAP or TRAP5b (Table 3).

**Response of hormones to RT or PLY.** To examine our hypothesis that the changes in BAP and TRAP5b following RT or PLY were associated with TEST, COR, or PTH, we examined the acute changes in plasma concentrations of the hormones using a one-factor repeated-measures ANOVA to test for a main effect of time during the 2 h postexercise (Table 4). In general, plasma COR significantly decreased during the 2 h following each exercise trial (Table 4). Likewise, plasma PTH significantly decreased during the 2 h following each exercise trial (Table 4) and, following PLY-Fed and RT-Fasted, had returned to PRE by 2 h following exercise. A main effect of time was detected for plasma TEST during the 2 h following the PLY-Fed and PLY-Fasted trials, but not following the RT trials. The response of TEST following PLY-Fed and PLY-Fasted was variable, showing both increases and decreases significantly from PRE during the 2 h following each RT or PLY trial, a one-factor repeated-measures ANOVA was performed for each trial to determine the main effect of time. Plasma BAP concentrations did not change significantly from PRE concentration during the 2 h following the exercise trials, except following the PLY-Fasted trial. During the PLY-Fasted trial, BAP exhibited a transient decline and then returned to PRE concentration during the 2 h following exercise (Table 2); however, upon post hoc analysis, none of the time points following exercise was significantly different than PRE. By contrast, TRAP5b declined transiently and returned to PRE concentration during the 2 h following each exercise trial (Table 2). Two hours following RT or PLY, plasma BAP and TRAP5b concentrations were not different than PRE; moreover, BAP and TRAP5b at 24 h were not significantly different than before exercise following any trial (Table 2). To test for main and interaction effects of exercise mode (i.e., RT vs. PLY) and feeding status (i.e., Fed vs. Fasted) on bone turnover markers, a 2 × 2 ANOVA was performed using the AUC for BAP and TRAP5b as the dependent variables. There were no main effects or interactions of exercise mode or feeding status for BAP or TRAP5b (Table 3).

**Results**

**Response of bone turnover markers to RT or PLY.** Participant characteristics are displayed in Table 1. Mean daily energy, lipid, carbohydrate, and protein intake were 2,755 ± 162 kcal (35.6 ± 2.7 kcal/kg, 96 ± 11 g, 357 ± 27 g, and 107 ± 9 g, respectively). Mean calcium and vitamin D intakes were 1,235 ± 219 mg/day and 6 ± 2 µg/day (240.6 ± 79.5 IU/day), respectively. Participants met the recommended dietary allowances (RDA) for calcium (1,000 mg/day); however, they did not meet the RDA for vitamin D (600 IU/day or 15 µg/day) (14). To determine whether bone turnover markers changed a two-tailed, paired *t*-test was performed. All statistical analyses were performed using SPSS, version 16.0. Statistical significance was established at the α-level of 0.05 for all analyses.

**Study 1**

### Table 1. Participant characteristics

<table>
<thead>
<tr>
<th>Anthropometric Measures</th>
<th>Values (± SE)</th>
<th>n = 12 subjects. BMI, body mass index; DXA, dual-energy X-ray absorptiometry; BMC, bone mineral content; BMD, bone mineral density.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>181.1 ± 1.3</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.1 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.1 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>Physical activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>h/wk</td>
<td>5.3 ± 0.8</td>
<td></td>
</tr>
<tr>
<td>kcal/wk</td>
<td>3.978 ± 0.64</td>
<td></td>
</tr>
<tr>
<td>Site-specific bone measurements by DXA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFR, cm²</td>
<td>2.962 ± 1.33</td>
<td></td>
</tr>
<tr>
<td>BMD, g/cm²</td>
<td>1.26 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMC, g</td>
<td>46.3 ± 2.5</td>
<td></td>
</tr>
<tr>
<td>BMD, g/cm²</td>
<td>1.08 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>Lumbar spine (L₁–L₄)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMC, g</td>
<td>84.6 ± 4.3</td>
<td></td>
</tr>
<tr>
<td>BMD, g/cm²</td>
<td>1.12 ± 0.04</td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SE, n = 12 subjects. BMI, body mass index; DXA, dual-energy X-ray absorptiometry; BMC, bone mineral content; BMD, bone mineral density.

### Table 2. Study 1 changes in bone turnover markers for each exercise trial

<table>
<thead>
<tr>
<th></th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAP, U/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE</td>
<td>17.1 ± 2.7</td>
<td>14.0 ± 2.9</td>
<td>16.0 ± 2.6</td>
<td>14.4 ± 2.3</td>
</tr>
<tr>
<td>POST</td>
<td>17.2 ± 2.6</td>
<td>13.9 ± 2.9</td>
<td>16.1 ± 2.7</td>
<td>14.4 ± 2.5</td>
</tr>
<tr>
<td>15 min</td>
<td>16.0 ± 2.6</td>
<td>13.3 ± 2.5</td>
<td>14.5 ± 2.6</td>
<td>13.5 ± 2.2</td>
</tr>
<tr>
<td>30 min</td>
<td>16.0 ± 2.4</td>
<td>12.9 ± 2.7</td>
<td>14.5 ± 2.4</td>
<td>13.8 ± 2.2</td>
</tr>
<tr>
<td>1 h</td>
<td>14.1 ± 2.3</td>
<td>13.2 ± 2.9</td>
<td>14.4 ± 2.4</td>
<td>13.0 ± 2.3</td>
</tr>
<tr>
<td>2 h</td>
<td>17.7 ± 2.3</td>
<td>13.0 ± 2.7</td>
<td>14.9 ± 2.6</td>
<td>13.4 ± 2.6</td>
</tr>
<tr>
<td>24 h</td>
<td>15.3 ± 1.9</td>
<td>13.8 ± 2.4</td>
<td>16.1 ± 2.6</td>
<td>13.7 ± 2.6</td>
</tr>
<tr>
<td>Main effect for time</td>
<td><em>P</em> = 0.043</td>
<td><em>P</em> = 0.511</td>
<td><em>P</em> = 0.055</td>
<td><em>P</em> = 0.435</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAP5b, U/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE</td>
<td>2.7 ± 0.4</td>
<td>2.8 ± 0.5</td>
<td>2.8 ± 0.5</td>
<td>2.8 ± 0.6</td>
</tr>
<tr>
<td>POST</td>
<td>2.7 ± 0.4</td>
<td>2.8 ± 0.5</td>
<td>2.7 ± 0.5</td>
<td>2.7 ± 0.5</td>
</tr>
<tr>
<td>15 min</td>
<td>2.5 ± 0.4*</td>
<td>2.6 ± 0.4*</td>
<td>2.6 ± 0.4*</td>
<td>2.6 ± 0.5*</td>
</tr>
<tr>
<td>30 min</td>
<td>2.6 ± 0.4</td>
<td>2.6 ± 0.4*</td>
<td>2.6 ± 0.5*</td>
<td>2.5 ± 0.4</td>
</tr>
<tr>
<td>1 h</td>
<td>2.7 ± 0.4</td>
<td>2.7 ± 0.5</td>
<td>2.7 ± 0.5</td>
<td>2.7 ± 0.5</td>
</tr>
<tr>
<td>2 h</td>
<td>2.7 ± 0.4</td>
<td>2.8 ± 0.5</td>
<td>2.9 ± 0.6</td>
<td>2.7 ± 0.5</td>
</tr>
<tr>
<td>24 h</td>
<td>2.7 ± 0.5</td>
<td>2.8 ± 0.5</td>
<td>3.0 ± 0.6</td>
<td>2.8 ± 0.5</td>
</tr>
<tr>
<td>Main effect for time</td>
<td><em>P</em> = 0.018</td>
<td><em>P</em> = 0.004</td>
<td><em>P</em> &lt; 0.001</td>
<td><em>P</em> = 0.015</td>
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</tbody>
</table>

Values are untransformed means ± SE, n = 12 subjects. PLY, plyometrics; RT, resistance training; BAP, bone-specific alkaline phosphatase; TRAP5b, tartrate-resistant acid phosphatase 5b; PRE, before exercise; POST, after exercise. Main effects for time during the 2 h following RT or PLY were determined by repeated-measures ANOVA. Significant main effect for time was followed up with post hoc pairwise comparisons [least significant difference (LSD)]. *Significantly different than PRE (*P* < 0.05) determined by post hoc pairwise comparisons. There were no significant differences between PRE and 24 h determined by a two-tailed, paired *t*-test (*P* < 0.05).
relative to PRE at different time points following exercise (Table 4).

Plasma COR and TEST concentrations at 24 h following the Fed (i.e., PLY-Fed and RT-Fed), but not Fasted (i.e., PLY-Fasted and RT-Fasted) trials were significantly greater than PRE (Table 4). Plasma PTH concentration 24 h following PLY-Fed was significantly greater than before exercise, but not following PLY-Fasted, RT-Fasted, or RT-Fed (Table 4).

To test whether the acute changes in bone turnover markers and hormones were different between exercise mode (i.e., RT vs. PLY) or energy status (i.e., Fed vs. Fasted), we performed a two-factor ANOVA using the AUC. The results of this analysis did not detect any significant effects of exercise mode or energy status. To test whether the acute changes in BAP or TRAP5b during the 2 h postexercise were associated with acute changes in hormones, bivariate relationships between the cumulative changes in BAP and TRAP5b and the cumulative changes in TEST, COR, and PTH were examined using Pearson’s correlations. The AUC of TRAP5b was positively correlated with the AUC of PTH ($r = 0.452$, $P = 0.001$). There were no other significant associations between changes in hormones and BAP or TRAP5b.

**Study 2**

The purpose of study 2 was to determine whether the response of bone turnover markers observed during study 1 differed from time-of-day variation in the bone turnover markers during a fasted, no-exercise CON trial. A second purpose of study 2 was to examine the response of an additional marker of bone formation (OC) and bone resorption (CTX) to a single bout of RT or PLY.

**Response of bone turnover markers to CON trial.** Following the CON trial, which took place at the same time of day as the exercise trials, i.e., beginning between 6:00 and 7:00 AM, plasma BAP concentration decreased significantly (Table 5). Plasma OC, TRAP5b, and CTX concentrations did not significantly change following CON (Table 5). Plasma BAP concentration was significantly different from CON at 2 h determined by a two-tailed, paired $t$-test ($P < 0.05$).

### Table 3. Study 1 area under the curve for bone turnover markers and hormones during 2 h postexercise

<table>
<thead>
<tr>
<th>Bone turnover markers</th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAP, $U^{-1}\cdot min^{-1}$</td>
<td>$-176 \pm 86$</td>
<td>$-87 \pm 65$</td>
<td>$-209 \pm 85$</td>
<td>$-115 \pm 80$</td>
</tr>
<tr>
<td>TRAP5b, $U^{-1}\cdot min^{-1}$</td>
<td>$-5 \pm 4$</td>
<td>$-5 \pm 10$</td>
<td>$-4 \pm 7$</td>
<td>$-11 \pm 12$</td>
</tr>
<tr>
<td>Hormones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COR, $\mu g \cdot dl^{-1}\cdot min^{-1}$</td>
<td>$-359 \pm 72$</td>
<td>$-318 \pm 67$</td>
<td>$-608 \pm 74$</td>
<td>$-393 \pm 101$</td>
</tr>
<tr>
<td>PTH, $ng \cdot ml^{-1}\cdot min^{-1}$</td>
<td>$-2,163 \pm 934$</td>
<td>$-2,557 \pm 872$</td>
<td>$-2,070 \pm 840$</td>
<td>$-1,429 \pm 485$</td>
</tr>
<tr>
<td>TEST, $ng \cdot dl^{-1}\cdot min^{-1}$</td>
<td>$-9,718 \pm 2,642$</td>
<td>$-9,529 \pm 4,776$</td>
<td>$-3,152 \pm 8,225$</td>
<td>$-11,550 \pm 5,072$</td>
</tr>
</tbody>
</table>

Values are untransformed means ± SE; $n = 12$ subjects. COR, cortisol; PTH, parathyroid hormone; TEST, testosterone. A 2 × 2 ANOVA was used to test for differences between exercise mode (i.e., RT vs. PLY) and feeding status (i.e., fed vs. fasted) on bone turnover markers.

### Table 4. Study 1 changes in hormones for each exercise trial

<table>
<thead>
<tr>
<th>COR, $\mu g/dl$</th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>17.9 ± 1.4</td>
<td>15.5 ± 0.9</td>
<td>17.7 ± 1.1</td>
<td>14.3 ± 1.0</td>
</tr>
<tr>
<td>POST</td>
<td>13.2 ± 0.8*</td>
<td>13.3 ± 1.0</td>
<td>17.3 ± 1.3</td>
<td>15.0 ± 1.4</td>
</tr>
<tr>
<td>15 min</td>
<td>11.6 ± 0.8*</td>
<td>12.3 ± 0.9*</td>
<td>15.2 ± 1.1</td>
<td>13.1 ± 1.2</td>
</tr>
<tr>
<td>30 min</td>
<td>10.1 ± 0.8*</td>
<td>10.2 ± 1.1*</td>
<td>14.5 ± 1.4</td>
<td>11.8 ± 1.1</td>
</tr>
<tr>
<td>1 h</td>
<td>9.7 ± 0.8*</td>
<td>9.5 ± 0.9*</td>
<td>10.9 ± 0.8*</td>
<td>11.4 ± 1.5*</td>
</tr>
<tr>
<td>2 h</td>
<td>9.7 ± 0.9*</td>
<td>10.9 ± 0.9*</td>
<td>9.6 ± 0.7*</td>
<td>10.7 ± 1.1*</td>
</tr>
<tr>
<td>24 h</td>
<td>16.9 ± 1.1</td>
<td>18.4 ± 1.3†</td>
<td>17.3 ± 1.6</td>
<td>18.1 ± 1.4†</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>$P &lt; 0.001$</td>
<td>$P &lt; 0.001$</td>
<td>$P &lt; 0.001$</td>
<td>$P = 0.002$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PTH, $ng/ml$</th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>64.7 ± 11.1</td>
<td>41.7 ± 6.6</td>
<td>56.6 ± 10.7</td>
<td>50.7 ± 11.8</td>
</tr>
<tr>
<td>POST</td>
<td>64.5 ± 14.9</td>
<td>58.4 ± 14.0</td>
<td>56.1 ± 14.2</td>
<td>46.6 ± 12.3</td>
</tr>
<tr>
<td>15 min</td>
<td>50.7 ± 10.6*</td>
<td>43.0 ± 9.8</td>
<td>38.8 ± 9.7</td>
<td>34.2 ± 9.3*</td>
</tr>
<tr>
<td>30 min</td>
<td>43.5 ± 9.8*</td>
<td>34.2 ± 8.1</td>
<td>34.4 ± 9.0</td>
<td>30.7 ± 8.3*</td>
</tr>
<tr>
<td>1 h</td>
<td>47.0 ± 9.7*</td>
<td>30.6 ± 3.6*</td>
<td>36.6 ± 8.7</td>
<td>33.1 ± 7.4*</td>
</tr>
<tr>
<td>2 h</td>
<td>41.9 ± 8.4*</td>
<td>40.9 ± 9.5</td>
<td>39.5 ± 8.2</td>
<td>37.5 ± 9.8*</td>
</tr>
<tr>
<td>24 h</td>
<td>59.7 ± 9.0</td>
<td>57.4 ± 9.5†</td>
<td>67.1 ± 11.5</td>
<td>59.8 ± 11.1</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>$P &lt; 0.001$</td>
<td>$P &lt; 0.001$</td>
<td>$P = 0.018$</td>
<td>$P &lt; 0.001$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEST, $ng/dl$</th>
<th>PLY-Fasted</th>
<th>PLY-Fed</th>
<th>RT-Fasted</th>
<th>RT-Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>917 ± 67</td>
<td>844 ± 81</td>
<td>984 ± 189</td>
<td>756 ± 71</td>
</tr>
<tr>
<td>POST</td>
<td>862 ± 63</td>
<td>924 ± 103</td>
<td>950 ± 163</td>
<td>867 ± 94</td>
</tr>
<tr>
<td>15 min</td>
<td>805 ± 63*</td>
<td>960 ± 144</td>
<td>907 ± 188</td>
<td>824 ± 93</td>
</tr>
<tr>
<td>30 min</td>
<td>789 ± 64</td>
<td>767 ± 97</td>
<td>917 ± 149</td>
<td>784 ± 83</td>
</tr>
<tr>
<td>1 h</td>
<td>803 ± 84</td>
<td>777 ± 93</td>
<td>818 ± 146</td>
<td>729 ± 80</td>
</tr>
<tr>
<td>2 h</td>
<td>710 ± 66</td>
<td>834 ± 96</td>
<td>999 ± 219</td>
<td>849 ± 126</td>
</tr>
<tr>
<td>24 h</td>
<td>965 ± 77</td>
<td>929 ± 89†</td>
<td>991 ± 156</td>
<td>1,010 ± 162†</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>$P = 0.028$</td>
<td>$P = 0.026$</td>
<td>$P = 0.410$</td>
<td>$P = 0.322$</td>
</tr>
</tbody>
</table>

Values are untransformed means ± SE; $n = 12$ subjects. Main effects for time during the 2 h following RT or PLY were determined by repeated-measures ANOVA. Significant main effect for time was followed up with post hoc pairwise comparisons (LSD). *Significantly different than PRE ($P < 0.05$) determined by post hoc pairwise comparisons. †Significantly different than PRE at 24 h determined by a two-tailed, paired $t$-test ($P < 0.05$).
The RT and PLY trials in study 1 was due to the exercise and not time-of-day variation. In general, hormone concentrations decreased during the 2 h following PLY or RT. The cumulative decrease in TRAP5b did not differ between RT or PLY or between feeding or fasting, but was correlated with the cumulative reduction in PTH during the 2 h postexercise. Conversely, BAP did not change during the 2 h following RT or PLY, with the exception of PLY-Fasted, but declined significantly during the morning hours (i.e., each trial began between 6:00 and 7:00 AM) in the no-exercise CON trial. Thus RT or PLY appeared to prevent the natural decline in BAP that occurs during the morning (16). These results show that reductions in bone resorption and maintenance of bone formation markers occur during the 2 h following a single bout of RT or PLY.

Exercise-induced changes in bone turnover are initiated by mechanical deformation of the osteoblasts and osteocytes (43). In vitro, bone cells respond rapidly to mechanical strain, as evidenced by changes in gene expression and/or protein expression of bone turnover markers (30, 31, 36). For example, alkaline phosphatase expression by osteoblast precursors transiently increased starting 0.5 h following in vitro mechanical stimulation before returning to prestimulation levels 24 h later (30, 31). Thus there is evidence to support the biological plausibility of the acute response of TRAP5b and BAP observed in the present study, which suggests that bone turnover is acutely altered during the 2 h following a single bout of RT or PLY. Moreover, the acute response of bone turnover markers observed during the 2 h following a single bout of RT or PLY in the present study is consistent with that reported previously following a single bout of RT (49). Whipple et al. (49) reported no changes in BAP concentration following a single bout of RT or PLY in the present study is consistent with that reported previously following a single bout of RT (49). Similarly, Ashizawa et al. (3) reported that serum BAP concentration decreased 24 and 48 h following RT and serum TRAP5b concentration decreased 24 h following RT (3).

We hypothesized that the effects of exercise on bone turnover markers, regardless of exercise mode and feeding status, would be associated with exercise-induced changes in TEST, COR, or PTH, as these hormones all respond acutely to exercise (4, 12, 29, 35) and alter bone metabolism (7, 8, 47). In general, the present study found significant changes in COR, TEST, and PTH following either RT or PLY. The decrease in hormone concentrations observed may be a result of a lack of adequate loading and appropriate rest periods to induce changes in hormone concentration; however, changes in bone turnover may not be associated with short-term alterations in circulating hormone concentration. A novel result of the present study is that the RT and PLY sessions, which were designed to maximize the bone response, induced similar acute changes in circulating hormone concentrations (reviewed in Refs. 12, 29) and alter bone metabolism (7, 8, 47). In general, the present study found significant changes in COR, TEST, and PTH following either RT or PLY. The decrease in hormone concentrations observed may be a result of a lack of adequate loading and appropriate rest periods to induce changes in hormone concentration; however, changes in bone turnover may not be associated with short-term alterations in circulating hormone concentration. A novel result of the present study is that the RT and PLY sessions, which were designed to maximize the bone response, induced similar acute changes in circulating hormone concentrations (reviewed in Refs. 12, 29) and alter bone metabolism (7, 8, 47). In general, the present study found significant changes in COR, TEST, and PTH following either RT or PLY. The decrease in hormone concentrations observed may be a result of a lack of adequate loading and appropriate rest periods to induce changes in hormone concentration; however, changes in bone turnover may not be associated with short-term alterations in circulating hormone concentration. A novel result of the present study is that the RT and PLY sessions, which were designed to maximize the bone response, induced similar acute changes in circulating hormone concentrations (reviewed in Refs. 12, 29) and alter bone metabolism (7, 8, 47). In general, the present study found significant changes in COR, TEST, and PTH following either RT or PLY. The decrease in hormone concentrations observed may be a result of a lack of adequate loading and appropriate rest periods to induce changes in hormone concentration; however, changes in bone turnover may not be associated with short-term alterations in circulating hormone concentration. A novel result of the present study is that the RT and PLY sessions, which were designed to maximize the bone response, induced similar acute changes in circulating hormone concentrations (reviewed in Refs. 12, 29) and alter bone metabolism (7, 8, 47).

Table 5. Study 2 changes in additional markers of bone turnover for exercise trials

<table>
<thead>
<tr>
<th></th>
<th>PLY-Fed</th>
<th>RT-Fed</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAP, U/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE</td>
<td>11.6 ± 3.4</td>
<td>12.3 ± 2.9</td>
<td>20.3 ± 1.2</td>
</tr>
<tr>
<td>POST</td>
<td>10.3 ± 3.5</td>
<td>11.7 ± 3.1</td>
<td>19.1 ± 1.0*</td>
</tr>
<tr>
<td>1 h</td>
<td>9.7 ± 3.2</td>
<td>10.6 ± 2.2</td>
<td>17.7 ± 0.9*</td>
</tr>
<tr>
<td>2 h</td>
<td>10.4 ± 3.0</td>
<td>11.4 ± 3.1</td>
<td>18.9 ± 0.7</td>
</tr>
<tr>
<td>24 h</td>
<td>12.2 ± 2.9</td>
<td>12.2 ± 2.4</td>
<td>18.1 ± 1.1†</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>P = 0.164</td>
<td>P = 0.581</td>
<td>P = 0.013</td>
</tr>
<tr>
<td>TRAP5b, U/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE</td>
<td>2.6 ± 0.2</td>
<td>2.5 ± 0.2</td>
<td>2.8 ± 0.4</td>
</tr>
<tr>
<td>POST</td>
<td>2.6 ± 0.3</td>
<td>2.4 ± 0.2</td>
<td>2.7 ± 0.4</td>
</tr>
<tr>
<td>1 h</td>
<td>2.5 ± 0.3</td>
<td>2.5 ± 0.2</td>
<td>2.4 ± 0.3</td>
</tr>
<tr>
<td>2 h</td>
<td>2.5 ± 0.3</td>
<td>2.5 ± 0.2</td>
<td>2.5 ± 0.3</td>
</tr>
<tr>
<td>24 h</td>
<td>2.5 ± 0.3</td>
<td>2.6 ± 0.2</td>
<td>2.4 ± 0.3</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>P = 0.468</td>
<td>P = 0.519</td>
<td>P = 0.070</td>
</tr>
<tr>
<td>CTX, ng/ml</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE</td>
<td>15.4 ± 3.6</td>
<td>14.3 ± 2.5</td>
<td>11.4 ± 1.5</td>
</tr>
<tr>
<td>POST</td>
<td>12.6 ± 0.8</td>
<td>13.3 ± 2.2</td>
<td>13.6 ± 2.3</td>
</tr>
<tr>
<td>1 h</td>
<td>15.1 ± 3.7</td>
<td>13.4 ± 2.6</td>
<td>12.3 ± 1.8</td>
</tr>
<tr>
<td>2 h</td>
<td>14.9 ± 3.4</td>
<td>14.4 ± 2.7</td>
<td>12.5 ± 2.2</td>
</tr>
<tr>
<td>24 h</td>
<td>13.3 ± 2.8</td>
<td>16.3 ± 5.0</td>
<td>15.5 ± 3.3</td>
</tr>
<tr>
<td>Main effect for time</td>
<td>P = 0.134</td>
<td>P = 0.362</td>
<td>P = 0.825</td>
</tr>
</tbody>
</table>

Data are untransformed means ± SE (n = 5). CON, control; OC, osteocalcin; CTX, COOH-terminal telopeptide of type I collagen. Significant main effect for time was followed up with post hoc pairwise comparisons (LSD). *Significantly different than PRE (P < 0.05). †Significantly different than PRE at 24 h assessed by a two-tailed, paired t-test (P < 0.05).

Concentration was significantly reduced at 24 h compared with PRE following CON. In contrast, plasma OC was significantly greater at 24 h compared with preexercise (Table 5).

Response of additional bone turnover markers to RT or PLY. Following RT-Fed or PLY-Fed, plasma OC concentrations did not significantly change (n = 5) (Table 5). A significant main effect for time was detected for plasma CTX following PLY-Fed, but the response during the 2 h following exercise was variable, with both increases and decreases observed (Table 5). CTX did not change significantly following RT-Fed. In general, the plasma concentrations of bone turnover markers had returned to preexercise values at 2 h post-RT or -PLY; likewise, 24-h values were similar to PRE concentrations with rare exceptions (Table 5).

Discussion

This study is the first to compare the acute response of plasma bone turnover markers to a single bout of RT vs. the response to PLY. The results of the present study suggest that the response of bone turnover markers to exercise may be undetected, if the markers are not measured at the appropriate time following exercise. During the 2 h following a single bout of RT or PLY, we observed a transient decrease in the bone resorption marker TRAP5b. Because TRAP5b remained unchanged during the no-exercise CON trial in study 2, we concluded that the reduction in TRAP5b observed following
multiplanar movements, and induces ground reaction forces that are fourfold greater than body weight (48). In addition, enhanced fluid flow through the cannicular system of the osteocytes may amplify the strain signals that induce increases in bone mass (37). In the present study, we did not detect a difference in the acute bone turnover marker response between RT and PLY. However, it must be noted that our hypothesis was based on the assumption that the type of loading that induces the greatest changes in bone mass also causes the greatest acute changes in markers of bone turnover. Our assumption was based on the ability of relatively short-term changes in bone turnover markers to predict changes in BMD in response to drug treatments for osteoporosis (15). However, at present, it is unknown if a similar relationship holds for exercise-based interventions, i.e., whether short-term changes in bone turnover markers induced by exercise are associated with long-term changes in bone mass.

We also hypothesized that energy status (i.e., Fed vs. Fasted) would modify the acute bone turnover response to RT or PLY because an overnight fast reduces the diurnal variation of bone resorption markers (10, 20), and relatively short-term changes in energy balance (5 days or less) have been shown to alter bone turnover markers (21). Short-term alterations in energy balance also alter the acute response of bone turnover markers to a single exercise bout (51). However, we did not detect a significant effect of energy status on changes in bone turnover markers following a single bout of RT or PLY. Compared with previous studies that reported an effect of moderate energy restriction (i.e., 5 days of ~1,000 or 500 kcal/day) on bone turnover markers (21), the 10-h fast undertaken in the present study likely was not large enough of an energy deficit to alter the response of bone turnover markers to exercise. Likewise, it is possible that there is a relationship between energy status and exercise mode, i.e., mechanical loading characteristics, such that the effect of energy status is dependent on the strength of the mechanical loading signal. That is, mechanical loading of sufficient magnitude may partially offset bone loss that occurs during long-term suboptimal energy intake (13, 26).

The present study, although limited by the small sample size, has numerous strengths. First, the cross-over design allowed each participant to serve as his own control in subsequent trials, thereby reducing interindividual variability and increasing statistical power. The RT and PLY sessions were designed to induce a maximal response in bone turnover markers and included the insertion of rest periods to allow bone cells to sense and recover from the fluid shift through the skeleton that influences bone remodeling (33, 34, 40). Participants were not currently engaged in PLY or RT, which likely would have suppressed the acute response of the hormones (1) and/or bone turnover markers to RT or PLY. In addition, all participants had normal TEST, COR, and PTH; none had osteoporosis; and all consumed adequate amounts of calcium to minimize inter-subject variation in the bone turnover marker response due to these potential confounders. Before each trial, subjects consumed the same meal that they consumed before the first trial to minimize variation associated with differences in energy and nutrient intake.

The present study has a number of limitations. The study design was not fully randomized, as the subjects performed the Fasted trials in random order, followed by the Fed trials in random order. Cumulative bone resorption during the 2 h post-RT or -PLY was estimated using the AUC for serum concentrations at various time points, rather than urinary CTX. Although we attempted to control dietary intake within subject by having participants consume the same diet before and during the exercise trials, differences in both macronutrient and micronutrient intake between trials might have affected the bone turnover marker response. In addition, average vitamin D intake was less than the RDA. Because vitamin D influences bone mass and muscle function, it is possible that suboptimal intakes might have altered the acute bone turnover response to exercise. Finally, a wide age range (24–62 yr) of subjects was included, and age has been reported to influence bone turnover.

In conclusion, we observed a significant transient decline in the bone resorption marker TRAP5b during the 2 h following a single bout of RT or PLY that was not observed during the CON trial. Thus we concluded that the changes in TRAP5b observed following the RT and PLY trials in study 1 were due to exercise and not time-of-day variation. Conversely, BAP did not change during the 2 h following RT or PLY, but declined significantly during the CON trial. Thus RT and PLY appeared to prevent the normal decline in BAP that occurs during morning hours. Exercise mode (i.e., PLY vs. RT) and energy status (i.e., Fed vs. Fasted) had no effect on the bone turnover marker response during the 2 h following exercise. The results of the present study suggest that the timing of the measurement of bone turnover markers relative to the last exercise bout is important for detection of exercise-associated changes in bone turnover markers, as the markers returned to preexercise values within 2 h of RT or PLY.

ACKNOWLEDGEMENTS

We thank all of the subjects who took part in the study for their time and efforts. The authors thank Matthew O. Widzer for assistance in blood draws, exercise administration, and assay procedures.

GRANTS

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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