The Effects of High-Impact and Resistance Exercise on Urinary Calcium Excretion

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Although physical activity is known to improve bone mineralization, it is unclear whether this occurs through altered absorption and/or excretion. The purpose of this study was to investigate the effects of a high-impact and resistance-training exercise program versus a period of restricted physical activity on urinary calcium excretion. Ten healthy, moderately active men (27.0 ± 5.8 yr) participated in a 3-wk randomized crossover study. Participants were assigned to complete either a period of daily participation in exercise including high-impact and resistance-training activities (EX) or a period of restriction in physical activity (NE) for 7 consecutive days. After a 1-wk washout period, participants completed the opposite trial. During both phases, participants consumed four 8-oz servings of low-fat (1%) milk daily and avoided other dietary and supplemental sources of calcium. Urine was collected throughout the final 72 hr of each study phase. Urinary calcium and sodium excretions were 14.7% ± 17.1% and 15.8% ± 9.9% lower (p < .05), respectively, during the EX phase than the NE phase. These results occurred despite participants consuming more (p < .05) sodium during the EX phase than the NE phase. These results suggest that healthy, moderately active men excrete significantly less urinary calcium concurrent with lower sodium excretion during a week of performing high-impact and resistance-training exercises versus a week of restricted physical activity. The reduction in urinary loss of calcium might be at least partially responsible for improved bone mineralization that has been observed during periods of greater physical activity.

Keywords: physical activity, resistance training, metabolism, nutrition

Osteoporosis is a condition of reduced bone mass that results in increased bone fragility and fractures (Flynn, 2003). Approximately 10 million Americans have been diagnosed with osteoporosis, and it has been estimated that one in two women and one in four men over the age of 50 years will have an osteoporosis-related fracture in their lifetime (Hampton, 2004). Adequate intake of dietary calcium and participation in physical activity are vital factors in the development of

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peak bone mass during adolescence and the prevention of bone loss during adulthood (Weaver, 2000b).

Although physical activity, primarily weight-bearing high-impact exercise and resistance training, is known to improve bone mineralization, the mechanism of action and effects on dietary calcium requirements are unclear (Weaver, 2000a). Specker (1996) described a significant interaction between dietary calcium and exercise such that bone shape and density can be improved when increases in both occur. Because serum calcium concentrations are under very tight control, to achieve enhanced bone mineralization a positive shift in calcium balance must occur (Flynn, 2003). Researchers have speculated that this shift is accomplished by improved calcium absorption caused by exercise (Zittermann et al., 2000). Alternatively, or perhaps additionally, renal calcium retention might be increased during periods of physical activity because of greater bone mineralization. Paradoxically, researchers of numerous exercise interventions have suggested that urinary calcium excretion is not affected (Bullen, O’Toole, & Johnson, 1999; Martin, Davis, Campbell, & Weaver, 2007) or is higher after exercise (Ashizawa, Fujimura, Tokuyama, & Suzuki, 1997; Ashizawa et al., 1998).

Bullen et al. (1999) examined the effects of a single bout of running at moderate intensity for 45 min on 24-hr calcium excretion in untrained men. They detected no significant differences in urinary calcium losses between the exercise day and the preceding nonexercise day (Bullen et al.). Dietary calcium and dietary sodium were not controlled or assessed, however, which might have interfered with the accurate interpretation of the results for differences in calcium excretion. Ashizawa et al. (1998) also examined the influence of a single bout of resistance exercise on urinary calcium excretion in untrained men. Twenty-four-hour urine samples were collected during a preexercise control day, the exercise day, and 3 postexercise days. Participants received daily standardized diets including 840 mg of calcium. They excreted more urinary calcium on the exercise day than on the control day. Calcium excretion tended to be lower on the 3 postexercise days than on the control day (Ashizawa et al., 1998). The design of that study did not allow for the determination of the effects of more consistent exercise training on daily calcium excretion. In a well-controlled study, Martin et al. (2007) detected no difference in urinary calcium excretion in women participating in daily 1-hr sessions of low-impact cycling exercise versus exercise restriction.

Research to date has not assessed the effects of daily participation in high-impact exercise and resistance training on urinary calcium losses during an extended time period. Moreover, there has been little attempt to control the levels of dietary intake of calcium and sodium during the days of testing, both of which greatly affect urinary calcium excretion (Branca & Valtuena, 2001). The purpose of this study was to investigate the effects of a daily exercise regimen including both high-impact and resistance-training exercise versus a period of restricted physical activity on urinary calcium excretion when physical activity and dietary calcium are maintained at consistent levels throughout a 1-week period. Our hypothesis was that during a period of greater physical activity, urinary calcium excretion would be lower than during a period of restricted physical activity, which might allow for skeletal calcium accretion.
Methods

Participants

Ten healthy men age 18–40 years (27.0 ± 5.8 years) with a mean body-mass index of 27.2 ± 3.4 kg/m² were recruited using advertisements at San Diego State University. All participants were moderately active, exercising 2–6 hr/week (3.7 ± 1.4 hr/week) and regularly engaging in weight-bearing, endurance activities such as running, stair climbing, or weight lifting. Exclusion criteria included smoking, lactose intolerance, renal disease, or orthopedic injury. Each participant was given a through description of the study, and written informed consent was obtained. The protocol was approved by the San Diego State University Institutional Review Board.

Study Design

Participants were randomly assigned either to participate in a high-impact and resistance-training exercise regimen (EX phase) or to refrain from physical activities (NE phase) for 7 consecutive days. After a 1-week washout period, participants were crossed over to the other condition.

The EX phase of the study consisted of 20 min of jogging at 65–70% of age-predicted maximum heart rate (220 – age), five resistance exercises performed with an elastic resistance band involving major muscles of the upper limbs (three sets of 10 repetitions each), and jumping off a 2-ft-high box onto a noncarpeted surface. All participants progressed from 10 to 50 jumps per day in 10-jump increments over the first 5 days. On Days 5, 6, and 7 of the EX phase, 50 jumps per day were performed. Exercise activities were completed at locations of the participants’ choosing. During the NE phase, participants were instructed to refrain from exercise and remain as sedentary as possible. A list of activities to avoid (structured exercise, walking more than necessary, etc.) was provided to each participant. During both phases of the study, pedometers (Sportsline, Inc., Hazelton, PA) were worn and participants recorded all their daily physical activities in an exercise logbook to document adherence to the exercise stipulations.

During each phase of the study, milk was provided as a major source of dietary calcium. Participants were supplied with four 8-oz servings of low-fat (1%) milk to consume on a daily basis. The milk provided the participants with approximately 1,400 mg of calcium per day and 100% of the daily recommended intake for vitamin D. The participants were also given a list of foods to avoid that would contribute a significant amount of calcium, sodium, or oxalate to the diet, because these constituents greatly affect calcium excretion or absorption. Participants were also asked to keep their food and beverage selections consistent between the two study phases. Food records were obtained on the last 4 days of each 7-day phase (Days 4–7), and participants kept the food records of the first trial in their possession to serve as a reminder of food selection for the second trial. Participants were provided written instructions that included portion-size estimates, and a trained nutritionist also explained how to fill out the food records, as well as the importance of complete record collection. Estimates of daily dietary intake were computed using Nutritionist Pro diet-analysis software (version 3.0, Axxya Systems LLC, Houston, TX).
The first 4 days of each 7-day phase served as period of adjustment to the assigned exercise condition and the provided level of dietary calcium. Urine in 24-hr pools, beginning with the second void of the day and ending with the first void of the following day, were collected in acid-washed containers for the subsequent 3 days (Days 5–7). Completeness of collections was monitored and corrected using measurements of urinary creatinine.

Chemical Analysis

The 24-hr urine volumes were measured using a graduated cylinder, and aliquots were acidified with 1% (vol/vol) HCl and stored at −70 °C so they could be assessed simultaneously at the conclusion of the study to eliminate interassay variations. Urine creatinine content was assessed using a quantitative colorimetric kit from Stanbio, Inc. (Boerne, TX). Urine for mineral analyses was diluted with LaCl₃ (0.5%)-HCl (0.5 N). Urinary calcium and sodium were analyzed in triplicate using atomic absorption spectrometry (Unicam 969 Solaar Series, Cambridge, England). The coefficients of variation for urinary calcium and sodium were 1.6% and 0.7%, respectively. Urinary calcium, sodium, and creatinine excretions are the averages of the three consecutive 24-hr urine collections over the last 3 days of each study phase.

Statistical Analysis

The Statistics Package for Social Sciences (SPSS) computer software program for Windows, version 11.5 (SPSS Inc., Chicago, IL), was used for all statistical analysis. Demographic, biochemical, and dietary data are presented as $M \pm SD$. Paired-comparison $t$ tests were conducted to analyze the differences between the EX phase and NE phase. An alpha level of $p < .05$ was considered significant.

Results

All 10 participants successfully completed both phases of the study. They accumulated significantly ($p < .05$) more steps during the EX phase (10,389 ± 4,758 steps/day) than the NE phase (7,186 ± 3,824 steps/day). During the EX phase participants jogged 20.1 ± 2.1 min/day, and all box jumps and resistance-band exercises were completed.

Table 1 provides details of nutrient intake during the two study phases. Dietary records indicated no differences in calcium, energy, fat, carbohydrate, fiber, or protein intake between the NE phase versus the EX phase. Participants consumed significantly more sodium during the EX phase ($p < .05$) than during the NE phase.

Urinary calcium excretion was significantly ($p < .05$) greater (19 ± 21 mg/day) during the NE phase (173 ± 58 mg/day) than the EX phase (154 ± 72 mg/day; Figure 1). Figure 2 depicts significantly ($p < .05$) greater (631 ± 459 mg/day) urinary sodium excretion during the NE phase than the EX phase (3,935 ± 873 and 3,304 ± 802 mg/day, respectively). There were no significant differences in 24-hr urine volume (2.02 ± 0.81 vs. 1.72 ± 0.75 L/day, $p > .05$) or urinary creatinine (251 ± 68 vs. 373 ± 118 mg/day, $p > .05$) between the NE and EX phases.
Table 1  Dietary Intake During the NE and EX Phases, $M \pm SD$

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>NE</th>
<th>EX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (mg)</td>
<td>1,774 ± 197</td>
<td>1,809 ± 184</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>2,528 ± 1,036</td>
<td>2,894 ± 853*</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>2,271 ± 565</td>
<td>2,522 ± 624</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>65 ± 26</td>
<td>69 ± 25</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>327 ± 118</td>
<td>343 ± 98</td>
</tr>
<tr>
<td>Fiber (g)</td>
<td>27 ± 15</td>
<td>28 ± 11</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>122 ± 27</td>
<td>136 ± 25</td>
</tr>
</tbody>
</table>

*p < .05.

Figure 1  — Urinary calcium excretion during restricted physical activity (NE) and the high-impact and resistance-training phase (EX). Squares indicate means and error bars represent $SD$s. *Significantly lower than the NE phase ($p < .05$).

Figure 2  — Urinary sodium excretion during restricted physical activity (NE) and the high-impact and resistance-training phase (EX). Squares indicate means and error bars represent $SD$s. *Significantly lower than the NE phase ($p < .05$).
Discussion

The purpose of this study was to investigate the effect of participating in a 1-week high-impact and resistance-training exercise program versus a similar period of restricted physical activity on urinary calcium excretion when dietary calcium was held constant. Studies have demonstrated that high-impact and resistance-training exercises enhance total bone density and bone mass; however, it is not clear whether the increase in bone development necessitates more dietary calcium (Weaver, 2000a). The results of the current study indicated that healthy, moderately active men excreted significantly less urinary calcium during the EX phase than during the NE phase, which might at least partially account for greater bone production or less bone loss during periods of physical activity versus inactivity. The reduction of urinary calcium losses in participants completing the designed regimen of a combination of high-impact and resistance exercises versus a sedentary period amounted to approximately 19 mg/day on average. This degree of conservation might have a high degree of biological significance because exercise-induced bone production might not increase dietary needs by the total amount of bone calcium accrued.

Our findings are in accordance with a 7-month exercise-intervention study conducted by Hatori et al. (1993). Those researchers examined the effects of two different levels of exercise intensity on bone biochemical markers in 23 postmenopausal women. They found that compared with the baseline values, urinary calcium excretion decreased significantly after either a high-intensity or a moderate-intensity walking program (Hatori et al.). However, dietary intake of calcium and sodium was not reported for the postmenopausal women, making it difficult to assess whether the exercise program or dietary factors influenced the decrease in urinary calcium excretion. Nevertheless, reduced urinary calcium excretion might have partially contributed to the significantly greater bone-mineral density observed in the high-intensity group than in the control group.

Contrary to our findings, other research studies have demonstrated that various types of physical activities might increase urinary calcium excretion or produce no effect (Ashizawa et al., 1998; Bullen et al., 1999). However, those studies measured the effects of a single bout of exercise on urinary losses, and that type of research design does not allow for metabolic adaptations to occur that could alter the findings. If repeated days of exercise were examined, the researchers might have detected urinary calcium conservation as observed in the current study, which might serve as a mechanism to promote bone calcium accretion. Furthermore, the studies failed to adequately control for dietary intake of both calcium and sodium, which calls into question the validity of the results.

Ashizawa et al. (1998) reported that untrained young men (24.5 ± 0.7 years) receiving approximately 840 mg of calcium per day for 4 days before the exercise day excreted more urinary calcium after a single bout of resistance exercise. In contrast, Bullen et al. (1999) examined the effects of a single bout of running at moderate intensity for 45 min on calcium excretion in untrained men (23.9 ± 3.2 years) and found no significant differences in urinary calcium excretion between the exercise day and the nonexercise day. However, dietary calcium and sodium were not controlled, and the researchers also noted that half the participants consumed less than 1,000 mg of calcium during both days of the study (Bullen et al.).
The recommended daily calcium intake for men 18–40 years old is 1,000 mg (Institute of Medicine [U.S.], Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, 1997). Summarized research in a meta-analysis indicates that physical activity appears to have little effect on bone-mineral density when participants consume less than 1,000 mg of dietary calcium per day (Specker, 1996). On average, our participants consumed approximately 1,800 mg of calcium per day, which is well above the current adequate intake for calcium and at a level that should have limited the potential interference that inadequate calcium intake could exert on bone turnover, because a positive shift in calcium balance with exercise might not occur if calcium intake is not at or above an optimal level.

A possible mechanism for the exercise-induced decrease in urinary calcium excretion seen in our study might be a decrease in urinary sodium excretion. It is well known that dietary sodium influences urinary calcium excretion because calcium and sodium share the same transport system in the kidney (Heaney, 2006). Urinary sodium excretion is approximately equal to dietary sodium intake, provided that dermal losses resulting from factors such as sweating are not substantial (Holbrook et al., 1984). Heaney suggests that urinary calcium rises approximately 40 mg for every 2,300 mg of dietary sodium ingested. It is interesting that participants in the current study excreted less sodium and calcium during the EX phase than during the NE phase even though sodium intake was greater during the EX phase. Inadvertent underreporting of sodium intake during the NE phase because of hidden sodium in commercially prepared foods or added table salt might be a possible explanation for the lower sodium intake but greater sodium excretion during the NE phase. However, the decrease in urinary sodium excretion brought about by exercise is in accordance with previous research (Zappe, Bell, Schwartentruber, Wideman, & Kenney, 1996). Zappe et al. demonstrated that young adult men excreted less urinary sodium after 3 days of repeated low-intensity exercise (50% of VO2max); however, they did not measure 24-hr urinary calcium excretion. Hence, additional research is needed to determine whether a reduction in urinary calcium excretion from repeated bouts of exercise is induced by a decrease in urinary sodium excretion.

The reduction of urinary calcium excretion during the EX phase might have also occurred to partially offset possible increased dermal calcium losses. Under minimal sweating conditions, dermal calcium loss is estimated to be 63 mg/day in adults (Charles, Jensen, Mosekilde, & Hansen, 1983). However, substantial exercise-induced sweat calcium losses (>100 mg) have been reported in men (Klesges et al., 1996; O’Toole et al., 2000). In a study examining the effects of long-term intense training on bone-mineral density, Klesges et al. demonstrated that male athletes training 4 hr/day in hot and humid conditions lost on average 422 mg of dermal calcium. Furthermore, increased dermal losses have also been observed with moderate physical activity. Chu, Margen, and Costa (1975) studied 16 healthy young men in a metabolic unit and found that their sweat, induced by 40 min of walking at 3 mph at a 10% grade in ambient conditions, contained on average 25 mg of calcium. However, the researchers of both studies noted no decrease in urinary calcium to counteract the sweat calcium loss from the exercise (Chu, Margen, & Costa; Klesges et al.). Furthermore, Klesges et al. only obtained urine samples after training sessions, which might not accurately reflect total daily urinary calcium excretion (Klesges et al.). Chu et al.’s failure to note decreases in
urinary calcium excretion might have been the result of the type of exercise performed. Walking might not have elicited a positive change in calcium metabolism; several studies have reported that walking programs have little effect on preventing bone loss (Kohrt, Bloomfield, Little, Nelson, & Yingling, 2004). Martin et al. (2007) reported that strenuous cycling for 8 days had a modest impact on dermal calcium losses in 26 premenopausal sportswomen who consumed a controlled diet containing approximately 450 mg of calcium per day with an additional 400 mg of calcium supplementation but did not affect urinary calcium excretion during the last 4 days (Martin et al.). However, given the type of exercise completed, that study protocol would not have been expected to produce similar urinary calcium excretion differences that occurred in men participating in the high-impact and resistance-training activities employed in the current study. The lack of dermal calcium data from the current study prevents us from determining whether the decrease in urinary calcium excretion during the EX phase occurred to compensate for excessive dermal calcium losses. Future studies should examine whether the decrease in urinary calcium excretion with repeated days of high-impact and resistance-training exercise is a compensatory mechanism for an increase in dermal calcium excretion in men.

Another limitation of our study is that fecal calcium excretion was not measured. In a study examining the complete calcium intake, absorption, and excretion data in 191 adult female inpatients in a metabolic ward, Heaney, Recker, and Ryan (1999) found a significant inverse relationship between urinary and endogenous fecal calcium. They determined that for every 0.41-mg decrease in urinary calcium, endogenous fecal calcium increased 1.0 mg (Heaney et al.). Hence, it is critical to measure both urinary and fecal excretion to accurately assess the effects of exercise on overall calcium balance and to determine the influence of physical activity on dietary calcium requirements.

The goal of this study was to assess the effects of a resistance-training exercise program versus a similar period of restricted physical activity on urinary calcium excretion, which is only one of the major components of calcium balance. Sweat and fecal calcium are also both crucial components of total calcium balance, and the lack of these data is a limitation of our study. However, we believe that our results highlight the need for more comprehensive calcium-balance research because they open the possibility that less calcium is excreted during a period of increased bone-building-type exercises that might contribute to the positive calcium balance associated with bone formation. Researchers have demonstrated increases in urinary and fecal calcium that resulted in negative calcium balance during bed rest (LeBlanc et al., 1995). Calcium-balance changes that occur with bed rest versus normal activity might serve as a reasonable analog for the possible metabolic effects of a period of increased physical activity versus a period of restricted physical activity.

The exercise activities required during the EX phase of the study were unsupervised and were completed by the participants at a location of their choosing, which is another limitation of our study. However, participants maintained detailed exercise logs during the EX and NE phases, which does provide some assurance of compliance to the exercise stipulations.

In summary, this study demonstrated that healthy, moderately active men excrete significantly less urinary calcium during a week of performing high-impact
and resistance-training exercises than during a week of restricted physical activity. The results suggest that men compensate for increased physical activity with a reduction of renal calcium losses. Future studies should examine total calcium excretion (urine, fecal, and sweat) to determine whether a positive calcium balance occurs with participation in an exercise regimen consisting of high-impact and resistance-training exercises.

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**References**


