Interrupted Vs. Uninterrupted Training on BMD During Growth

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Interrupted vs. Uninterrupted Training on BMD during Growth


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Abstract

This study compared a resistance training program where the exercise was uninterrupted (UT, i.e., continuous exercise) against a resistance training program where the exercise was interrupted (IT, i.e., exercise sessions during a training day) for enhancing bone morphology and bone mineral density (BMD) in maturing animals. The total volume of work performed between the two resistance training programs was equivalent by design. Twenty-four young male rats were randomly divided into Control (n = 8), UT (n = 8) and IT (n = 8) resistance trained groups. The UT and IT groups were conditioned to climb a vertical ladder with weights appended to their tail. A 3-day workload of 6 wkks. After the 6-wk program, total osteocalcin was not significantly different between groups, whereas the adjusted urinary deoxypyridinoline (DOPD) was significantly lower for both UT (81.03 ± 5.53) and IT (88.30 ± 7.25) compared to Control (128.13 ± 9.99). Tibial BMD was significantly higher for UT (0.222 ± 0.005 g/cm²) and IT (0.219 ± 0.005 g/cm²) compared to Control (0.205 ± 0.004 g/cm²). There was no significant difference in DUO or BMD between UT and IT groups. The results indicate that both interrupted and continuous, uninterrupted resistance training programs were equally effective in stimulating bone modeling.

Introduction

Bone cells can respond to mechanical stress, especially dynamic physical exercise. The external forces imposed upon the bone via exercise needs to be of a sufficient magnitude to create a fluid flow within the lacunar-canalicular network to stimulate bone formation [3]. In this regard, resistance training (e.g., strength exercise) or high-impact activities (e.g., jumping) have been recognized to be more effective in stimulating bone formation when compared to endurance training [9,26]. In support, numerous human [1,4,16,19,22,27] and animal studies [7,9,13,15,20,28] have demonstrated the effectiveness of resistance training or high-intensity exercise in stimulating an osteogenic response and elevating bone mineral density. However, only a few studies have sought to determine the most effective training programs to elicit elevations in bone accrual during growth. Prior reports in prepubertal boys [2] and premenarchal girls [12] following various exercise programs demonstrated increases in bone mineral accrual compared with sedentary children. However, cross-sectional comparisons in humans are subject to confounding variables such as: genetics, dietary intake, and activity levels (to name a few). Additional challenges when studying children include matching the growth velocity between the exercise and control groups [2]. In this regard, the use of maturing animals can minimize many of these confounding variables, but identifying the mode of exercise to mimic resistance training has been previously a significant obstacle. In a prior study in maturing rats, we employed a vertical ladder climbing task with weight appended to an animal's tail and reported an elevation in bone mineral density [20]. In this study, we observed that lifting a heavy weight (i.e., total repetitions) in a given day would induce a greater increase in bone mineral density than uninterrupted resistance training in maturing male rats, culminating in increased mechanical bone strength.

Materials and Methods

Animals

The experimental protocol for this study was approved by the Chapman University Institutional Review Board and in accord with the Public Health Service policy on the use of animals for research. Twenty-four male Sprague Dawley rats (initially ~ 225 g) were obtained from River Laboratories (Wilmington, NJ, USA) and housed individually and maintained on a 12/12 hour light/dark cycle. The animals were acclimated to their living conditions for 1 week with food and water provided ad libitum. Then they were randomly assigned to either a Control group (n = 8), a resistance trained group where the animals performed continuous uninterrupted repetitions on a given training day (Uninterrupted, n = 8), or another resistance trained group where the animals performed repetitions that were interrupted at 3 separate times during a training day (Interrupted, n = 8). The group size of 8 was determined in a scientific manner (StatView Version 5.0, Salford Systems, Cary, NC, USA) based upon prior experience and using potential means and standard deviations from previous reports.

Resistance training

The strength training regimen has previously been described [20]. Briefly, the animals engaged in a vertical ladder-climbing task in which weights were appended to the rat's tail. One repetition along the 1 meter length of the ladder required 26 total lifts by the animal (or 13 lifts per limb). The resistance trained animals were operantly conditioned to climb the ladder in order to avoid a water source or water inside the cage. The exercised animals trained 3 days/week for a total of 6 weeks. The control animals were handled on the same days as the trained groups in order to minimize any stress attributable to handling. All animals were weighed at the beginning of the week to monitor weight gains and, for the resistance trained animals, to determine the amount of weight to append to their tails for the remainder of the week. The resistance trained animals started with 30% of their body mass appended to their tail, and each week the resistance was elevated by 30% of their body mass until they were carrying 150% of their body mass by the beginning of week 5, where they matched this resistance until the end of week 6. For the Interrupted group, the animals performed 6 consecutive ladder climbs on a given training day. The 6 ladder climbs constituted the maximum amount of consistent repetitions the interrupted animals could achieve. For the Interrupted group, the animals performed 2 ladder climbs 3 times during a training day where 45 seconds separated a bout of exercise. Thus, the total number of repetitions (i.e., total repetitions) in a given day was equivalent between the Uninterrupted and Interrupted groups. The resistance (%) body mass appended to their tail plus that of the resistance weight) was higher than the resistance weight alone for all time points. The total number of repetitions served to equate the total volume of work between Uninterrupted and Interrupted groups throughout the 6-week training period.

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The mechanical properties of bone were measured using a three‐submerged in saline for three scans and the coefficient of variation for repeated scans

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Prodigy, module (version 6.81) was used to assess the bone mineral density of the tibia and bone mechanical properties. Flexor hallucis longus was rapidly dissected from the right hindlimb and immediately frozen for the subsequent measurement of deoxypyridinoline and creatinine. A microplate reader (MaxLine, Molecular Devices Corp., Sunnyvale, CA, USA). A microplate reader (MaxLine, Molecular Devices Corp., Sunnyvale, CA, USA) was used to express the protein content in the flexor hallucis longus per

Con = control group (n = 8), UT = uninterrupted resistance trained group (n = 8), and IT = interrupted resistance trained group (n = 8). Maximum load to failure (Force in Newtons) and energy to failure (EJ (area under the load-deformation curve in Newtons × mm)) were expressed. The total protein in the flexor hallucis longus (muscle) per 100 g of body weight to help normalize these differences. In support, examining the flexor hallucis longus relative to the final body weight for each animal revealed that in resistance trained groups it was significantly greater that in controls (data not shown). Deoxypyridinoline (nml/l) was corrected for urine concentration or dilution, by dividing by the corresponding creatinine concentration (nml/l) and expressed as the adjusted urinary DPD. Except for the training volume, an energy absorption prior to failure were significantly greater for Uninterrupted and Interrupted groups compared to controls (Table 2), but were not significantly different between Uninterrupted and Interrupted groups (p=0.497 and p=0.436, respectively).

Discussion

Fig. 2. Bone mineral density (BMD) for the left tibia from Controls (Con, n = 8), Uninterrupted resistance trained group (UT, n = 8), and Interrupted resistance trained group (IT, n = 8). Significant difference vs. Con.

Table 2

Bone mechanical properties from 3-point bending test

Table 3

Adjusted urinary deoxypyridinoline (DPD) concentrations (nml/l) from Controls (Con, n = 8), Uninterrupted resistance trained group (UT, n = 8), and Interrupted resistance trained group (IT, n = 8). Significant difference vs. Con.

Table 1

Body mass and flexor hallucis longus, protein content

Con

IT

UT

Control (n = 8), UT = uninterrupted resistance trained group (n = 8), and IT = interrupted resistance trained group (n = 8). Maximum load to failure (Force in Newtons) and energy to failure (EJ (area under the load-deformation curve in Newtons × mm)) were expressed. The total protein in the flexor hallucis longus (muscle) per 100 g of body weight to help normalize these differences. In support, examining the flexor hallucis longus relative to the final body weight for each animal revealed that in resistance trained groups it was significantly greater that in controls (data not shown). Deoxypyridinoline (nml/l) was corrected for urine concentration or dilution, by dividing by the corresponding creatinine concentration (nml/l) and expressed as the adjusted urinary DPD. Except for the training volume, an energy absorption prior to failure were significantly greater for Uninterrupted and Interrupted groups compared to controls (Table 2), but were not significantly different between Uninterrupted and Interrupted groups (p=0.497 and p=0.436, respectively).

Discussion

The current study demonstrated that both an uninterrupted and interrupted 6-week resistance training regimen (where the total volume of work was kept constant between Uninterrupted vs. Interrupted groups) effectively induced an increase in tibial bone mineral density in maturing male rats. After 6 weeks of training, the osteogenic response for both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline. The increased bone mineral density from both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline.

While the bone mineral density and bone strength were elevated in both Uninterrupted and Interrupted groups, there was no significant difference between Uninterrupted and Interrupted groups. Thus, our results did not support our initial hypothesis

However, when we expressed the protein content in the flexor hallucis longus per 100 g of body mass, there were significantly higher protein concentrations from both Uninterrupted and Interrupted groups compared to the Control group (Table 1). The bone mineral density in the left tibia of both the Uninterrupted (p = 0.024) and Interrupted (p = 0.029) groups was significantly greater than that of the Control group (Fig. 2). However, the bone mineral density was not significantly different between Uninterrupted and Interrupted groups (p = 0.930). Serum osteocalcin did not significantly differ between the Controls (31.6 ± 12.1 ngl/ml), Uninterrupted (42.6 ± 0.6 ngl/ml), and Interrupted (41.6 ± 6.5 ngl/ml) groups. In contrast, the adjusted urinary deoxypyridinoline was significantly lower in Uninterrupted (p = 0.04) and Interrupted (p = 0.002) groups when compared to the Control group, but did not significantly differ (p = 0.518) between the Uninterrupted and Interrupted groups (Fig. 3). However, the bone mineral density observed for Uninterrupted and Interrupted groups resulted in significant elevations in the biomechanical properties of the left tibia compared to controls as revealed from the three-point bending test. The force to failure

Discussion

The current study demonstrated that both an uninterrupted and interrupted 6-week resistance training regimen (where the total volume of work was kept constant between Uninterrupted vs. Interrupted groups) effectively induced an increase in tibial bone mineral density in maturing male rats. After 6 weeks of training, the osteogenic response for both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by an increase in serum osteocalcin, but a decrease in osteoclast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline. The increased bone mineral density from both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by an increase in serum osteocalcin, but a decrease in osteoclast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline.

The increased bone mineral density from both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by an increase in serum osteocalcin, but a decrease in osteoclast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline. The increased bone mineral density from both Uninterrupted and Interrupted groups was not attributable to an elevation in osteoblast activity, as indicated by an increase in serum osteocalcin, but a decrease in osteoclast activity, as indicated by a decline in the adjusted urinary deoxypyridinoline.
of a greater osteogenic response fromInterrupted compared to
Uninterrupted resistance training.
Consistent with prior studies using the ladder climbing task [8, 20],
we report an elevation in skeletal muscle protein in the flexor
hallucis longus to offer support of a training effect from the
exercise programs. Consistent with prior studies, we chose to observe
the mechanical load of the tibia in accord with the location of the
Flexor hallucis longus. The elevation in tibial bone mineral density in
accord with our prior study [1], is consistent with our prior study,
where we similarly observed an increase in bone mineral density from
animals carrying 150% body mass after 6 weeks of training [20]. In
contrast, Robling et al. [9] observed more balanced and elevated bone mineral density when interrupting the exercise bout into discrete sessions per training day, when compared to the continuous resistance
exercise programs. Given that bone deposition is specific to the
location of bone mineral density in accord with the location of the
tibia in growing rats.

To our knowledge, the current study constitutes only the second
interrupted resistance training study [20], employing a 6-hour interval be­
tween sessions. Umemura et al. [26] similarly reported, in a jump exercise program, no augmented response from a 6-hour interval be­
tween two daily exercise sessions (2 × 10 jumps separated by 3 hours) in
maturing animals. To our knowledge, the current study constitutes only the second
report specifically to examine, in growing animals, the impact upon bone mineral density when separating voluntary exercise
sessions into discrete intervals rather than performing continuous
repetitions in a single training bout. Umemura et al. [26] employed high-intensity (5 days/week) exercise regimens, whereas we
employed a moderate-intensity (3 days/week, for 6 weeks) protocol. Collectively, both of these reports in rats suggest that
interrupting a bout of exercise into discrete sessions during a training day is not as effective as a single bout of exercise performed
given a training day.

In contrast, Robling et al. [17,18] reported, in anesthetized ani­
mals, that a daily loading protocol of 4 hours was as effective as a loading protocol separated by 3 hours produced a significantly greater osteogenic response than a single, continuous bout of 360 loading cycles. The potential mechanism(s) for the difference between our re­
sults and that of Robling et al. [18] is beyond the scope of this study. However, we did not perform any strain gauging, we
therefore likely underestimate the comparison the ladder climbing task we
employed to the ulna loading protocol used by fortin et al. [17,18].
Next, we note several potential differences between the studies. As an example, we used conscious animals and a resistance training
program that incorporated bouts of exercise other every day. In contrast, Robling et al. [17,18] utilized a daily protocol. Despite the differences between our study and that of Robling et al. [17,18], we were able to achieve a
– 7.5% increase in bone mineral density in the tibia during the
6-week period. Robling et al. [17,18] observed a 7% increase in bone
mineral density in the tibia after 16 weeks. While an appropriate comparison between our resistance training protocol and the
loading protocol implemented by Robling et al. [17,18] is not possible with the speculation submitted by Ume­

mera et al. [26] that more time than the 4–5 hours we provided between intervals were required for the mechanical stimuli to be fully
available. We note that the age of the animal might be a factor for the different results. In the current study, all animals were
males, whereas the animals examined, were Robling et al. [17,18] used adult rats. Thus, it is

possible that the age of mature adult animals may yield contri­
butions to results contributed to growing infants.

Net bone deposition is dependent upon the amount of bone
formation compared to bone resorption. As such, an osteogenic
response can be estimated as the amount of bone formation,
depressed bone resorption compared to bone formation, or a combination of both. Our results suggest that
the training-induced increase in bone mineral density is attri­
butable to a decrease in bone formation. Yeh et al. [29] similarly observed a trained-induced elevation in bone formation (via treadmill exercise) in bone modeling from
maturating female rats in accord with the location of the
ulna, tibia and fibula. While our results are comparable with
Yeh et al. [29], we have no explanation for the lack of decline in bone remodeling.

Moreover, it is possible that the ascertainment of bone deposition is specific to the
location of bone mineral density. While we have demonstrated a significant increase in bone mineral density in the tibia, we
have not evaluated bone density in the femur or ulna. Therefore, the recovery period for the Interruption
training protocol are noteworthy, the most impor­
tant parameter related to the risk of fractures in the hip is the hip bone strength. While our results did
not suffice to recover bone strength in growing rats.

Therefore, to elucidate any maximal effectiveness of using multiple exercise
sessions within a given training day.

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