Effects of Physical Activity on Bone: What type of Physical Activity and how much is Optimal for Bone Health?

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Introduction

The lifetime risk for osteoporotic fractures is reported to be 40%-50% for females and 12%-22% for males [1]. Thus, females are a good target audience for counter measures against osteoporosis and osteoporosis-related fractures. Lifestyle, including physical activity and nutritional management, throughout life plays an important role in the maintenance of bone health. Strategies for preventing osteoporosis and osteoporosis-related fractures through physical activity in females include:

1. Maximizing peak bone mass in children, adolescents, and premenopausal women.
2. Preventing bone loss and vertebral fractures in postmenopausal women.
3. Preventing falls and hip fractures in older women.

The calcium, vitamin D, and vitamin K nutritional status also needs to be improved. Women with a bone mineral density (BMD) T score <2.5 require treatment with anti-fracture medicine. The purpose of exercise and sports activities differs from one age group to another.

Increased mechanical usage stimulates bone modeling, suppresses bone remodeling, and increases bone strength [2,3]. The higher peak bone strain that is loaded, the greater the gain in bone mass and strength [2,3]. Because the peak bone strain is important for controlling bone modeling and remodeling, high-impact mechanical loading appears to be effective for increasing bone mass and strength. Experimental studies using turkeys and roosters have demonstrated the regulation of bone mass by mechanical strain; a higher strain magnitude is beneficial for increasing the bone mass, but a lower cycle number with a physiological strain magnitude is sufficient to realize a significant increase in bone mass [4,5]. Another experimental study using young growing rats demonstrated that five jumps per day were sufficient to increase bone mass and strength [6]. These results suggest that high-impact exercise is effective for strengthening bone but that a low number of repetitions are sufficient to obtain a significant effect from exercise.

The peak ground reaction force was evaluated for exercise models including walking, running, 5-repetition squats, jump squats, and depth jumps [7]. Depth jumps appear to offer the greatest potential as an osteogenic stimulus. Appendicular bones, such as the femur and tibia, are vigorously exposed to mechanical loading through high-impact exercise, while axial bones, such as the spine, can be effectively exposed through high-magnitude exercise (resistance training).

To maximize peak bone mass in children, adequate calcium intake and exercise are important. Because the peak bone mineral content (BMC) velocity is reached at Tanner stage 4 (menarche occurs between Tanner stages 3 and 4), exercise before menarche appears to be useful for effectively increasing bone mass in girls [8]. Specker and Binkley [9] showed that calcium supplementation (1000 mg/day) and exercise consisting of jumping, hopping, and skipping (30 min/day, 5 days/week for 1 year) increased the bone size and BMC of the leg in children (3-5 years old). Fuchs et al. [10] also showed that a jumping exercise (61 cm jumping, 100 times (30 min/day, 3 days/week for 7 months) increased the femoral neck and lumbar spine BMC in girls (average age: 7.6 years). Heinonen et al. [11] clarified that high-impact exercise (20 min jumping, 2 days/week for 9 months) increased the femoral neck and lumbar spine BMC in premenarcheal girls but not in postmenarcheal girls. These results suggest that high-impact exercise together with adequate calcium intake is useful for stimulating bone growth in girls. During the prepubertal stage, the bone may be particularly responsive to high-impact exercise, which is attainable in brief sessions of jumping activity. Because the bones of young growing children are osteogenic, both the femoral neck and the lumbar spine respond to mechanical loading. Interventions may therefore be needed before menarche (during the growth spurt) in children to maximize the peak bone mass effectively.

Regarding the maximization of the peak bone mass in adolescents and premenopausal women, cross-sectional studies have compared the BMD among female athletes. Nikander et al. [12] categorized exercise loading into five types:

1. High-impact (maximal vertical jumps with ground impacts).
2. Odd-impact (rapid turns and stops while spurting/running with ground impacts).
3. High-magnitude (maximally applied muscle force in slow well-coordinated movements without ground impact).
4. Repetitive low-impact (ground impacts that occur during long-lasting running performance at a relatively constant speed).
5. Repetitive non-impact (applied muscle forces occurring during-lasting performance without ground impacts).

High-impact and odd-impact female athletes have a higher BMC of the distal tibia and tibial diaphysis, compared with non-athletes [12]. In rhythmic gymnastics female athletes, the BMD is higher in the...

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left leg than in the right leg at the femoral neck, greater trochanter, and Ward’s triangle [13], supporting an association between impact exercise and bone gain. Mudd et al. [14] reported that gymnastics, softball, field hockey, and soccer athletes had a higher BMD than running and swimming/diving athletes, suggesting that sport activities requiring weight-bearing are related to a higher BMD in athletes, while long-distance running and swimming are related to a lower BMD. A meta-analysis study demonstrated that brief (<30 min/day, 4.6 days [range: 2-7 days]/week) high-impact exercise improves the BMD at the femoral neck, but not at the lumbar spine, in premenopausal women [15]. However, another meta-analysis study demonstrated that impact activity with high-magnitude exercise (average dose: 1 hr/day, 3 days/week [except one study, with 100 jumps+100 repetitions of resistance exercise, 3 days/week]) increased femoral neck and lumbar spine BMD in premenopausal women [16], suggesting the beneficial effect of a combined program with impact activity and resistance training on clinically relevant skeletal sites.

Regarding the prevention of bone loss after menopause and vertebral fractures, the lumbar spine BMD has been frequently evaluated in postmenopausal women. Both walking and high-magnitude exercises modestly increase lumbar spine BMD, and a combination of these exercises is more useful for increasing BMD [17,18]. Our study confirmed that walking exercise (8000 steps/day, 4 days/week for 1 year) modestly increased the lumbar spine BMD in postmenopausal women with osteopenia/osteoporosis [19]. In this study, outdoor walking was designed using a target heart rate calculated with Karvonen’s formula, corresponding to 50% of the maximal oxygen consumption [19]. Each subject learned a walking speed that corresponded to each target heart rate by using a treadmill at the beginning of the exercise program [19]. A meta-analysis study demonstrated that impact activity with high-magnitude exercise (average dose: 2 sets/day, 3 days/week) increased femoral neck and lumbar spine BMD in postmenopausal women [20], suggesting the effect of a combined program with impact activity and resistance training on clinically relevant skeletal sites. Sinaki et al. [21] reported back the muscle strengthening exercise (10 times/day, 5 days/week) with a backpack containing weights equivalent to 30% of the maximal isometric back extensor strength prevented vertebral fractures in postmenopausal women with osteoporosis.

To prevent falls and hip fractures, the safety of exercises is important for older women. The purpose of exercise should focus on the prevention of falls, although no evidence has shown that exercise reduces the incidence of hip fracture. Improvement of the vitamin D status is important (intake: ≥ 800 IU/day; 25(OH)D: ≥ 30 ng/mL) to reduce the incidence of falls and fractures [22,23]. According to an updated meta-analysis and the best-practice recommendations for exercise to prevent falls in older adults, exercise prevents falls (relative risk: 0.84), and programs that include balance exercises (higher doses: at least 2 hours/week; ≥ 50 hours over the trial period) and do not include walking exercise having the greatest effect on reducing falls. High-risk individuals should not be prescribed brisk walking programs [24]. The aim of walking in older women should be sunlight exposure to improve the vitamin D status (especially in northern countries where oily fish is not frequently consumed).

In conclusion, lifestyle (including physical activity and nutritional management) plays an important role in the maintenance of bone health throughout life in women. The optimal type and dose of exercise and sports activity that benefits female bone health appears to be age-specific (Table 1). Exercise and sports activity should be encouraged differently according to the age of individuals and the purpose of the exercise and sports activity.

**References**


**Table 1:** Optimal type and dose of exercise in maintaining bone health in females according to RCTs and meta-analyses.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Type of exercise/sport</th>
<th>Duration and frequency</th>
<th>Femoral neck</th>
<th>Lumbar spine</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children (Premenarcheal)</td>
<td>High-impact</td>
<td>20-30 min/day, 3.3 days/week</td>
<td>↑ BMC</td>
<td>↑ BMC</td>
<td>Higher BMD</td>
</tr>
<tr>
<td>Adolescents (School- and college-based sport activities (with weight-bearing))</td>
<td>Back muscle strengthening</td>
<td>10 times/day, 5 days/week</td>
<td>Incidence of vertebral fractures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Premenopausal Women</td>
<td>High-impact</td>
<td>&lt;30 min/day, 4.6 days/week</td>
<td>↑ BMC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact plus high-magnitude</td>
<td>1 hour/day, 3 days/week</td>
<td>↑ BMC</td>
<td>↑ BMC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postmenopausal Women</td>
<td>Impact plus high-magnitude</td>
<td>2 sets/day, 3 days/week</td>
<td>↑ BMC</td>
<td>↑ BMC</td>
<td></td>
</tr>
<tr>
<td>Older women</td>
<td>Balance</td>
<td>Higher doses: ≥ 2 hours/week</td>
<td>Incidence of falls</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RCT: randomized controlled trial, BMC: bone mineral content, BMD: bone mineral density.


