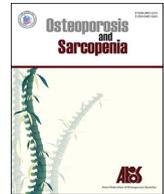




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## Review article

## School-based exercise interventions effectively increase bone mineralization in children and adolescents

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## ABSTRACT

Osteoporosis and fragility fractures have become major global public health concerns, and they can be prevented by maximizing peak bone mass during childhood and adolescence with weight-bearing physical activity, which can result in stronger and healthier bones that significantly decrease the risk of osteoporosis and fragility fractures in adulthood and the elderly years. From a public health perspective, implementing weight-bearing physical activity for children and adolescents is best achieved with school-based exercise interventions, and a review of school-based exercise interventions was conducted to determine their effectiveness in increasing bone mineral density (BMD) and/or bone mineral content (BMC). Seventeen studies were reviewed, all school-based exercise interventions utilized jumping exercises, and 15 of the 17 studies found at least one significant increase in measures of BMD and/or BMC for the total body, and/or at the hip, vertebrae, and/or wrist. One study that found no significant differences did report significant increases in bone structural strength, and the other study with no significant differences had exercises that measured and reported the lowest ground reaction forces (GRFs) of only 2–3 times body weight (BW), whereas the other studies that showed significant increase(s) in BMD and/or BMC had exercise with measured and reported GRFs ranging from  $3.5 \times$  to  $8.8 \times$  BW. School-based exercise interventions are time- and cost-efficient and effective in increasing BMD and/or BMC in children and adolescents, but must incorporate high-intensity exercise, such as high-impact jumping of sufficient GRFs, in order to significantly increase bone mineralization for osteoporosis and fragility fracture prevention later in life.

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## 1. Introduction

The World Health Organization (WHO) declares that osteoporosis is a major global public health problem that is highly prevalent in populations throughout the world [1]. Osteoporosis is a severe skeletal disease of reduced bone mineral density (BMD) that is clinically diagnosed as being 2.5 standard deviations below the adult peak mean [2], and this reduction of BMD decreases bone strength and increases its risk for fragility fractures. Fragility fractures are most prevalent at the hip, particularly the bone at the femoral neck; the vertebrae, particularly the bones of the lumbar spine; and at the wrist, such as the bone of the distal radius. Decreased BMD and diagnosed osteoporosis increase the risk of

fragility fractures in populations [3]. Osteoporosis affects hundreds of millions of individuals from all over the world [4], and the amount of people who are susceptible to fragility fractures is underestimated, as many fragility fractures occur in individuals who do not even meet the clinical definition of osteoporosis [5], and the majority of individuals who suffer from low-trauma fractures do not have osteoporosis based on its clinical definition [6]. Also considered to be a “silent” disease, as most individuals with osteoporosis or low BMD do not know that they are at risk of bone and fragility fractures until they actually occur, it is also currently incurable, as there are no present treatments that are capable of fully replenishing the reduced BMD.

The WHO reports that there are numerous ways to prevent osteoporosis and fragility fractures, though the most optimal approach is to have adequate amounts of calcium intake and weight-bearing physical activity all throughout the lifespan, but especially during youth such as childhood and adolescence when BMD can be maximized, and this enhances bone strength to

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prevent osteoporosis and fragility fractures later in life into adulthood [1]. During the lifespan, most bone acquisition happens during youth at childhood and adolescence, and it can continue to minimally increase in early adulthood, but then continuously decreases in later adulthood and into the elderly years. Thus, childhood and adolescence is when maximal peak bone mass should be attained, in which it can be maintained throughout the rest of the lifespan [7]. Furthermore, of the two main osteoporosis preventive behaviors of calcium intake and weight-bearing physical activity, weight-bearing physical activity is a more important factor than calcium intake in achieving maximal peak bone mass during youth [8], particularly if it is high-impact jumping or high-intensity running or resistance training, as that may have higher impact on bone mass [9]. And higher peak bone mass at youth with weight-bearing physical activity during youth is sustained into older adulthood [10]. Therefore, children and adolescents who engage in weight-bearing physical activity have the ability to attain higher maximal peak bone mass in order to most optimally prevent osteoporosis and fragility fractures later in life (Fig. 1).

As a global public health problem, the social ecological model can be used in public health practice to affect different amounts of populations through various levels of health [11]. Implementing community health interventions will have more of an impact on population health improvement than traditionally used individual health interventions, as they impact more people and directly connect to public health policy, which can implement, enforce and support wide-spread community health interventions to have a greater impact on population health (Fig. 2). With children and adolescents being optimal populations for osteoporosis and fragility fracture prevention due to their ability to most efficiently increase BMD, schools are an ideal location to implement community health interventions incorporating weight-bearing physical activity for this population in public health practice.

School-based exercise intervention studies have investigated what specific types of weight-bearing physical activities can improve bone health, particularly in the assessment of bone mineralization measured in BMD and/or bone mineral content (BMC). The purpose of this review is to determine if and how school-based exercise interventions may increase bone

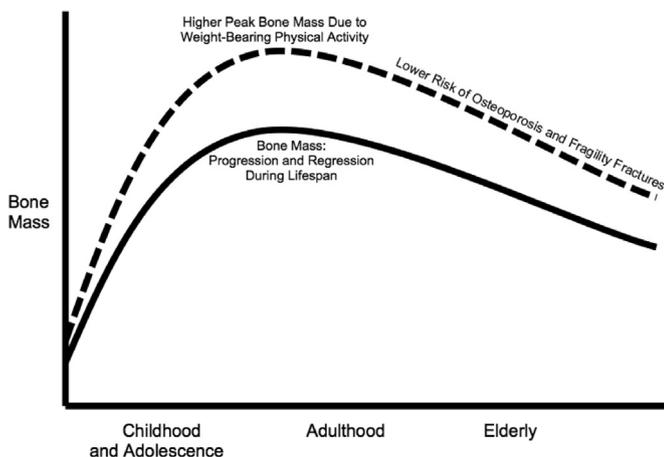
mineralization in children and adolescents, in order to find what types of exercises should be implemented in school settings to effectively increase BMD and/or BMC.

## 2. Review of the literature

A review of the literature using PubMed and Google Scholar was conducted, and search terms entered included “school,” “bone,” “exercise,” and/or “physical” for “physical activity” or “physical education.” After a thorough examination of all search results, there were numerous studies of school-based exercise interventions, and due to various deciding factors, 21 studies were considered to be most suitable for this review of school-based controlled exercise interventions as they utilized high-impact and/or high-intensity weight-bearing physical activity specifically designed to improve bone health. Of those 21 studies, 3 did not include a measure of bone mineralization, such as BMD or BMC, and were excluded from the review. In addition, 1 study was excluded that did not include a measure at a skeletal site of high susceptibility to fragility fractures, which resulted in 17 articles found to be studies of school-based exercise interventions of high-impact and/or high-intensity weight-bearing physical activity that measured bone mineralization in either BMD and/or BMC of children and/or adolescents in comparison to control participants (Fig. 3, Table 1). As all 17 studies investigated at least one school-based exercise intervention [12–28], 1 study compared 2 different school-based exercise interventions [12], and 1 study included school-based exercise and/or nutrition interventions [18]. Of the 17 school-based exercise interventions, 15 studies found at least one significant increase in measures of BMD and/or BMC [12,13,15–17,19–28], and of the 2 studies that did not find significant increases [14,18], 1 of those studies did report increases in other measures of bone strength [14], and the other study found no significant differences [18]. School-based exercise interventions varied in the types and amounts of exercises performed, though all interventions included sessions that were from 10 to 40 minutes ranging from 2 to 5 times per week, and the duration of these studies ranged from 7 months up to 43 months, with one study reaching 91 months due to inclusion of follow-up measures. Exercises were integrated into physical education classes and/or into activities at school [13–28], or as an after school activity [12]. All 17 studies measured school-based exercise intervention effects on BMD and/or BMC at various locations of the skeleton, such as the total body and skeletal sites that are common areas of fragility fractures, including the femoral neck, proximal femur and trochanter for the hip; the lumbar spine for the vertebrae; and the distal radius for the wrist.

For weight-bearing physical activity, every school-based exercise intervention used various forms of jumping activities, most of which consisted of high-impact jumps with many sessions as short as just 10 min [13–15,19,22–25,27,28]. High-impact jumping was shown to significantly increase BMD and/or BMC for the total body [12,15,17,20,21,24], at the hip [12,15–17,19–28] and the vertebrae [13,15,17,21,23,26,27]. High-impact loading at the hands also showed a significant increase at the wrist [13]. Of the 15 studies that found a significant increase in BMD and/or BMC, 14 of those 15 studies found a significant increase at the hip, which is the skeletal site where fragility fractures are most common and the consequences are most severe. One study also investigated the long-term effects of school-based exercise interventions with annual follow-up measures after the intervention had concluded, and showed lasting significant increases at the hip approximately 7 years after the intervention [16].

Of the 2 studies that did not find significant increases in BMD and/or BMC, one of those studies did measure and assess bone structural strength and found significant increases [14]. The other



**Fig. 1.** Bone health throughout the lifespan. The solid line represents the natural progression of bone mass increasing during childhood and adolescence into early adulthood, and then its natural regression of continuously decreasing into older adulthood and the elderly years, which increases the risk of osteoporosis and fragility fractures. The dashed line represents how weight-bearing physical activity creates larger increases in peak bone mass during childhood and adolescence, which leads to continuously higher bone mass into adulthood and the elderly years to reduce the risk of osteoporosis and fragility fractures.

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