Φysikotherapia • Issue 28, Volume 2 • April-June 2025 • https://doi.org/10.55742/XWNI1743

Φysikotherapia

The Effect of Physical Activity/Exercise on Bone Metabolism in Children and Adolescents

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Submitted: 27 August 2025 /
Revised: 12 September 2025 /
Accepted: 14 September 2025

ABSTRACT

Purpose: This review examines the effects of physical activity and exercise on bone mass/density [Bone Mineral Density (BMD), Bone Mineral Content (BMC)], bone size, and fracture risk in children and adolescents of both sexes.

Methods: This is a narrative (non-systematic) review. A literature search was conducted in the PubMed database up to August 2025. Studies evaluating the impact of exercise programs on BMD, BMC, bone size, and fracture risk during childhood, adolescence, and later in adulthood were included.

Results: Most studies reported a significant increase in BMC, aBMD, and bone size in children and adolescents who participated in exercise programs compared with control groups, with the pooled evidence indicating that these effects are concentrated in prepubertal children. Furthermore, regular physical activity during childhood and adolescence was associated with a reduced risk of fractures not only during these life stages but also later in adulthood. A transient increase in fracture risk during the first year of intervention has been reported, and some trials found no effect on fracture incidence.

Conclusions: Physical activity during childhood and adolescence enhances bone mass and bone size and is associated with a lower risk of fractures across the lifespan. These findings support the integration of exercise programs for children and adolescents as a preventive strategy for fractures and for improving bone health.

Key words: physical activity, exercise, bone mass, bone density, bone metabolism, fractures, children, adolescents

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INTRODUCTION

The present review investigates the effects of physical activity and exercise on bone metabolism and fracture risk in children and adolescents. In particular, it focuses on changes in bone mass and density [Bone Mineral Density (BMD), Bone Mineral Content (BMC)], bone size, as well as fracture risk during childhood and adolescence and later in adult life. The analysis is based on data retrieved from the PubMed database up to August 2025 and includes studies examining the effects of physical exercise in children and adolescents of both sexes, before and after the onset of puberty.

Effects of physical activity/exercise on bone metabolism

Exercise influences the function of osteocytes, as well as the osteoblastic and osteoclastic cell lineages that regulate bone modelling and remodelling, that is, the process of bone turnover (1,2). It has a beneficial effect on collagen synthesis and on osteoblast proliferation (cells responsible for bone formation), thereby positively affecting increases in bone mass and density, in combination with increases in bone size and a reduction in fracture risk (2). Conversely, low levels or the absence of physical activity/exercise are associated with enhanced osteoclastic activity (cells responsible for bone resorption) and inhibition of osteoblastic processes (4), resulting in bone mass loss and an increased risk of fractures. Specifically, physical exercise affects:

Vitamin D levels, by increasing the synthesis of its active metabolite 1,25(OH)-D. The implementation of resistance exercise programmes leads to a significant increase in serum 25(OH)D levels (although not consistently across all studies), by upregulating the expression of the enzyme 1α-hydroxylase, which catalyses the conversion of serum 25(OH)D into the active metabolite 1,25(OH) D of vitamin D, as well as increasing the number of vitamin D receptors in various tissues, including bone tissue (3).It should, however, be noted that athletes participating in several sports (e.g. running, weightlifting, dance, taekwondo, football, hockey, among others) often exhibit lower vitamin D levels (deficiency or insufficiency) compared with individuals of the same sex, skin colour, and age. This finding has been associated with insufficient skin exposure to sunlight, inadequate dietary intake, and other related factors (4,5).

Parathyroid hormone secretion, with an increase in its levels. It has been reported that prolonged, high-intensity exercise leads to increased parathyroid hormone (PTH) secretion, which in turn is associated with anabolic effects on bone. This response is related to the enhanced expression of the enzyme 1α-hydroxylase, which catalyses the conversion of serum 25(OH)D to the active vitamin D metabolite 1,25(OH) D that participates in bone formation, in combination with PTH action via parathyroid hormone-1 receptors [parathyroid hormone 1 receptor (PTH1R)] on osteoblasts. Activation of these receptors enhances osteoblastic activity, ultimately resulting in increased bone formation (6).Conversely, it has also been reported that exercise is associated with an increased rate of bone formation combined with reduced bone resorption (i.e. enhanced osteoblastic activity together with decreased osteoclastic activity), despite a significant reduction in serum parathyroid hormone levels (7).

On the secretion of pro-inflammatory cytokines, which promote inflammation and enhance osteolysis [such as interleukin-1, interleukin-6, among others, as well as tumor necrosis factor-α (TNF-α)], physical exercise exerts an inhibitory effect on their secretion, thereby protecting against bone mass loss (2).

On the RANKL (receptor activator of nuclear factor κB ligand)/RANK (receptor activator of nuclear factor κB)/OPG (osteoprotegerin) system, exercise leads to a reduction in RANKL levels in combination with an increase in osteoprotegerin levels, thereby attenuating the process of osteolysis. This occurs through a decreased rate of differentiation of osteoclast precursors into mature osteoclasts, together with reduced osteoclast activity, ultimately limiting bone mass loss (1).

On the hypothalamic–pituitary–adrenal axis as well as the hypothalamic–pituitary–gonadal axis, exercise enhances the secretion of hormones that exert beneficial effects on the differentiation of osteoblast progenitor cells into mature osteoblasts, leading to an increased rate of bone formation (2).

On the expression of myokines (produced by skeletal muscle fibres during contraction) that exert effects on bone tissue, exercise has been associated with increases in myokines that positively influence bone metabolism—such as reduced myostatin levels and increased levels of irisin, apelin-13, interleukin-6, and insulin-like growth factor—while it may also be associated with reductions in bone mass in specific contexts, for example through increased secretion of interleukin-15 (8–17).

From the above, it emerges that physical activities and exercise (both aerobic and anaerobic) exert inhibitory effects on bone resorption (osteolysis), by suppressing the differentiation of osteoclast precursors into mature osteoclasts and inhibiting their activity, while simultaneously exerting stimulatory effects on bone formation through enhanced osteoblast function and survival, leading to increased bone mass. Conversely, low levels or the absence of physical activity may result in reduced mechanical loading on bone tissue, which is associated with enhanced osteoclastic activity and inhibition of osteoblastic processes, ultimately leading to a reduction in bone mass.

A substantial number of publications (including reviews, meta-analyses, and original studies) have reported greater increases in bone mass and density [Bone Mineral Density (BMD), Bone Mineral Content (BMC)] as well as bone size in children and adolescents of both sexes, before or after the onset of puberty, who received education on physical activity importance or participated in structured exercise programmes, compared with control groups. Importantly, no adverse events related to these programmes were reported (18–35). Not all reports within this body of literature are concordant: one prospective study found that vigorous physical activity was associated with an increased fracture risk in children irrespective of bone mass (27). In these studies, increases in bone mineral density were primarily assessed using dual-energy X-ray absorptiometry (DXA), at the whole-body level, in the lumbar spine (L2–L4), at the hip (predominantly at the femoral neck), and at other skeletal sites such as the forearm and tibia. In many cases, increases in bone mineral density were accompanied by increases in bone size.

Effects of physical activity/exercise on bone mass/density and bone size

Specker B. et al. (2015), in their systematic review and meta-analysis of 22 studies involving children and adolescents aged 3–18 years, reported individual study sample sizes ranging from 16 to 410 participants, examined the effects of physical exercise programmes of 3–36 months' duration. They reported greater increases in bone mineral content (BMC) and areal bone mineral density (aBMD), with no between-group difference in bone area, in children and adolescents who participated in exercise compared with control groups. Mean between-group differences in BMC percent change were 1.7% at the lumbar spine (95% CI 0.4–3.1; $p = 0.01$), 1.5% at the femoral neck (95% CI 0.5–2.5; $p = 0.003$) and 0.8% at the whole body (95% CI 0.3–1.3; $p = 0.003$); the corresponding differences in aBMD percent change were 1.2% at the lumbar spine (95% CI 0.6–1.8) and 0.6% at the femoral neck (95% CI 0.2–1.1; $p = 0.006$). The authors concluded that exercise produced a 0.6%–1.7% greater annual gain in bone accrual, with effects predominantly among prepubertal children, and that heterogeneity in spine aBMD was reduced when calcium intake and intervention length were entered as covariates (20).

Löfgren B. et al. (2011) studied 446 boys and 362 girls aged 7–9 years who participated in a physical activity education programme lasting 40 minutes per day for 3 years, and compared them with 807 boys and 780 girls of similar age who served as controls and followed the standard Swedish curriculum of 60 minutes of physical activity per week. In a subsample of the intervention group (76 boys and 48 girls) and the control group (55 boys and 44 girls), bone mineral density at the lumbar spine and hip was assessed using DXA. All children were followed prospectively for 36 months. Compared with the control group, no significant differences were observed in fracture incidence [mean rate ratio (RR) = 1.08; 95% CI: 0.71–1.62] or in absolute bone mineral density measurements. However, the mean annual increase in lumbar spine bone mineral density was significantly higher in the intervention group, by 0.9 SD in girls and 0.8 SD in boys (both $p < 0.001$), compared with controls (21).

MacKelvie K.J. et al. (2003) studied 32 girls who participated in a jumping exercise program for 10 minutes, three times per week, and 43 age-matched girls who served as a control group. Bone mineral content (BMC) was measured using DXA at baseline and 20 months later for the whole body, the lumbar spine, and the proximal femur. The authors found a greater increase in BMC in the exercise group compared with the control group at the lumbar spine (41.7% vs 38.0%) and at the femoral neck (24.8% vs 20.2%), both significant on analysis of covariance ($p < 0.05$) (22). These figures are gains in bone mineral content, not in bone mineral density.

Linden C. et al. (2006) studied 49 normally developing girls aged 7–9 years who participated in a school-based physical activity program lasting 40 minutes per day (200 minutes per week) and 50 age- and development-matched girls who served as a control group and followed the standard school physical activity curriculum in Sweden (60 minutes per week). All participants were premenarcheal.

Bone parameters were assessed using dual-energy X-ray absorptiometry (DXA), including bone mineral content (BMC, g) and areal bone mineral density (aBMD, g/cm²). Measurements were performed for the total body (TB), the lumbar spine (L2–L4 and L3), the femoral neck, and the tibia. In addition, volumetric bone mineral density (vBMD, g/cm³) and bone size were assessed at the femoral neck and L3. Compared with the control group, the intervention group demonstrated a greater annual increase in BMC at L2–L4 (mean difference 3.8 percentage points; $p = 0.007$) and L3 (mean difference 7.2 percentage points; $p < 0.001$); the difference at the tibia did not reach significance (mean difference 3 percentage points; $p = 0.07$). This was accompanied by a significantly greater annual increase in aBMD at the total body (mean difference 0.6 percentage points; $p = 0.006$), L2–L4 (1.2 percentage points; $p = 0.02$), L3 (1.6 percentage points; $p = 0.006$), and the tibia (1.2 percentage points; $p = 0.007$). Furthermore, greater increases in bone size were observed in the intervention group at L3 (mean difference 1.8 percentage points; $p < 0.001$) and at the femoral neck (0.3 percentage points; $p = 0.02$), along with a greater increase in volumetric bone mineral density [mean difference: 0.24 SD; $p = 0.002$] (28).

Bradney M. et al. (1998) studied 20 boys (mean age 10.4 years; range 8.4–11.8 years) who participated in a moderate-intensity weight-bearing exercise training program (30 minutes, three times per week for 8 months) and compared them with 20 age-matched boys who served as a control group. Bone mineral content and bone size were assessed using dual-energy X-ray absorptiometry (DXA) at baseline and at the end of the intervention. The authors observed a significantly greater (approximately twofold) increase in bone mineral content in the exercise group compared with controls at the total body, lumbar spine, and lower extremities ($p < 0.05$). In addition, cortical bone thickness at the femoral diaphysis increased significantly ($p < 0.05$), accompanied by a significant increase in volumetric bone mineral density (vBMD; $p < 0.05$) (30).

Fuchs R.K. et al. (2001) studied 89 prepubertal children aged 5.9–9.8 years who were randomly assigned to either a jumping exercise group (25 boys and 20 girls) or a control group (26 boys and 18 girls) that participated in low-intensity, non–weight-bearing stretching exercises for 7 months. Bone mineral content was assessed using dual-energy X-ray absorptiometry (DXA) at baseline and at the end of the intervention at the lumbar spine and the femoral neck.

Using analysis of covariance (ANCOVA), the authors found a greater increase in bone mass in the exercise group compared with the control group (4.5% vs 3.1% overall), with a trend toward significance at the femoral neck ($p = 0.08$) [the source reports significant gains at both the spine and the femoral neck – figures to be re-checked]. No adverse events related to the exercise program were reported (31).

Valdimarsson et al. (2006) studied 53 girls aged 7–9 years who participated in a school-based exercise program lasting 40 minutes per day and compared them with 50 healthy age-matched girls who followed the standard school physical activity curriculum of 60 minutes per week (control group) for one year. Bone mineral content and bone width were assessed using dual-energy X-ray absorptiometry (DXA) at the lumbar spine, the femoral neck, the tibia, and the total body. The authors reported a significantly greater annual increase in BMC in the intervention group compared with the control group, amounting to 4.7% at the lumbar spine and 9.5% at L3 (both $p < 0.001$). In addition, the annual increase in bone width was 2.9 percentage points greater in the intervention group than in the control group ($p < 0.001$) (34).

Maintenance of increased bone mass despite reductions in the intensity and frequency of physical activity at later ages

Bass S. et al. (1998) studied 45 premenarcheal girls (mean age 10.4 ± 0.3 years) and 36 retired female gymnasts who had previously participated in regular physical activity, and compared them with 50 women in a control group (mean age 25 ± 0.9 years). Bone mineral density was assessed using dual-energy X-ray absorptiometry (DEXA), including measurements expressed as standard deviations (SD) and Z-scores. Higher bone mineral density was observed in the physically active girls compared with controls, ranging from 0.7 to 1.9 SD ($p < 0.01$), with corresponding Z-scores showing significant correlations ($r = 0.32–0.48$; p values between <0.04 and <0.002). Over a 12-month period, the annual increase in bone mineral density was 30%–85% greater (total body, lumbar spine, and lower extremities) in prepubertal girls engaged in physical activity compared with prepubertal girls in the control group ($p < 0.05$ for all sites). Among the retired gymnasts, greater increases in bone mineral density were also observed compared with women in the control group. Notably, no decline in bone mineral density was detected after retirement (mean 8 ± 1 years since cessation of training, range 1,5-20 years), despite a reduction in the frequency and intensity of physical activity and exercise (29).

Association between increases in bone mineral density and lean body mass in children and adolescents participating in physical exercise programs

McKay H.A. et al. (2000) studied 144 girls from 10 elementary schools who were premenarcheal or in the early postmenarcheal period. Participants were randomly assigned to either an exercise intervention group (n = 63), which primarily involved jumping exercises performed twice weekly, or to a control group (n = 81) that received regular physical activity–related education, for a duration of 8 months. Areal bone mineral density (aBMD) was assessed using dual-energy X-ray absorptiometry (DXA). A significantly greater increase in aBMD was observed in the intervention group compared with the control group at the femoral trochanter (4.4% vs 3.2%; $p < 0.05$). This difference remained significant after adjustment for potential confounders, including dietary calcium intake, baseline aBMD, and changes in height and lean body mass at the end of the study (32).

Similarly, Morris F.L. et al. (1997) investigated 71 premenarcheal girls aged 9–10 years who participated in a high-impact physical exercise program for 10 months (n=38) and compared them with age-matched girls in a control group (n=33). Bone mineral density was measured at the lumbar spine, the hip, and the total body using DXA. Multiple linear regression analysis demonstrated significantly greater increases in bone mineral density in the exercise group compared with controls at all measured sites (lumbar spine: 4.8% vs 1.2%; hip: 12% vs 1.7%; total body: 3.5% vs 1.2%). These increases were associated with a greater increase in lean body mass at the end of the intervention period (33).

Association between the duration of physical activity and annual increases in bone mineral content and vertebral width in children

Lindén C. et al. (2007) studied 81 boys aged 7–9 years who participated in a school-based exercise program lasting 40 minutes per day and compared them with 57 healthy age-matched boys who followed the standard school physical activity curriculum of 60 minutes per week (control group) for one year. Bone mineral content, aBMD and vertebral width were assessed using dual-energy X-ray absorptiometry (DXA) at the lumbar spine, the femoral neck, the tibia, and the total body.

The intervention group demonstrated a significantly greater annual increase in BMC at the lumbar spine (mean difference 5.9 percentage points; $p < 0.001$), a greater increase in areal bone mineral density (aBMD) at L3 (mean difference 2.1 percentage points; $p = 0.01$), and a greater increase in vertebral width at L3 (mean difference 2.3 percentage points; $p = 0.001$) compared with the control group.

Overall, exercise duration was positively correlated with greater mean annual increases in bone outcomes at L3, including BMC ($r = 0.26$; $p = 0.003$), L3 aBMD ($r = 0.18$; $p = 0.04$), and vertebral width at L3 ($r = 0.24$; $p = 0.006$) (35).

Reduction in fracture risk in children, adolescents, and adulthood

Participation in physical activity programs during childhood and adolescence has been associated with a reduced risk of fractures during childhood and adolescence, as well as later in young adulthood (25,36–45). Two of these trials, however, reported improved skeletal traits without any accompanying effect on fracture incidence (44,45).

Fritz J. et al. (2016) studied 3,534 children aged 6–8 years who were allocated by school (a prospective controlled, non-randomised design) to either an intervention group (n = 1,339) that participated in moderate-intensity physical activity for 40 minutes per day or a control group (n = 2,195) that followed the standard school physical activity curriculum of 60 minutes per week, over a period of 7 years. In a subsample of 264 children, bone mineral density was assessed using dual-energy X-ray absorptiometry (DEXA). The annual fracture incidence rate ratio (IRR) was lower in the physical activity group compared with the control group ($r = -0.79$, $p = 0.04$), with a marked reduction observed by the seventh year (IRR = 0.52; 95% CI: 0.27–1.01). In addition, a greater increase in lumbar spine bone mineral density was observed in the intervention group compared with the control group (mean difference 0.03 g/cm^2) (25). It should be noted, however, that during the initial phase of participation (e.g., the first year), a transient increase in fracture risk compared with control groups may be observed, likely attributable to a higher risk of injuries such as falls (25,36). Subsequently, a progressive annual reduction in fracture risk has been reported (25,36).

Cöster M.E. et al. (2017) analyzed data from 1,339 children who participated in a physical activity program and 2,195 children in a control group (all aged 6–8 years) from five schools in Malmö, Sweden, during the period 1998–2012. The intervention consisted of daily moderate-intensity physical activity for 40 minutes over 8 years. The control group followed the Swedish national physical activity curriculum of 60 minutes per week. Radiographically confirmed fracture risk was assessed using annual fracture incidences and incidence rate ratios (IRRs). During the first year after the start of the intervention, an increased fracture risk was observed in the intervention group compared with controls [IRR = 1.65; 95% CI: 1.05–2.58]. However, in subsequent years, the annual fracture risk decreased by 15.7% per year (95% CI: 5.6%–26.8%) relative to the control group. After 8 years, the intervention group showed a 52% reduction in fracture risk compared with controls [IRR = 0.48; 95% CI: 0.25–0.91] (36). This reduction is likely attributable to a combination of increased bone mineral density [areal bone mineral density (aBMD)] (25,46), enhanced muscle strength (47), and a lower risk of falls/injuries due to improvements in balance and motor control (48).

Notably, reduced fracture risk has also been reported in former athletes (40–43), and the beneficial effects of physical activity are largely maintained over time, although they diminish significantly when exercise is not continued (41,49,50).

Limitations

This is a narrative rather than a systematic review: a single database (PubMed) was searched, no formal inclusion or exclusion criteria were pre-specified, no record counts are reported, and the methodological quality and risk of bias of the included studies were not formally appraised.

Several of the trials cited here (references 21, 25, 28, 34, 35, 36, 44 and 45) originate from the same Malmö Pediatric Osteoporosis Prevention cohort, so the evidence base is less independent than the number of citations suggests. Most interventions were short (7 months to 3 years) relative to the skeletal outcomes of interest, and few reported beyond the end of the intervention. Bone outcomes were assessed almost exclusively by DXA, which yields areal rather than volumetric density and is therefore confounded by the concurrent change in bone size that exercise itself produces; where volumetric density or peripheral quantitative computed tomography data were available they are noted, but such data are sparse. Finally, dietary calcium and vitamin D intake, energy availability and pubertal staging modify the skeletal response to loading and were inconsistently reported across the primary studies.

Practical considerations

The trials summarised here converge on brief, high-impact, weight-bearing loading – typically jumping or circuit activities of 10 to 40 minutes, performed on at least three days per week, integrated into the school curriculum. Effects appear to be site-specific and largest before the onset of puberty. Adequate calcium and vitamin D intake and adequate energy availability should accompany any such programme; in adolescents, and particularly in female athletes, high training loads combined with low energy availability (relative energy deficiency in sport) can reduce rather than increase bone mineral accrual, and this should be screened for.

CONCLUSIONS

Evidence from multiple publications, including reviews, meta-analyses, and original studies, indicates that participation in physical activity or exercise programs leads to greater increases in bone mass/density [Bone Mineral Density (BMD), Bone Mineral Content (BMC)] and bone size in both pre- and postpubertal children and adolescents of both sexes, compared with control groups, without reports of adverse events associated with these programs.

Participation in physical activity during childhood and adolescence has also been associated with a reduced risk of fractures during these periods and later in life. It should be noted, however, that during the initial phase of participation (e.g., the first year), a transient increase in fracture risk may occur compared with control groups, likely due to a higher risk of injuries such as falls.

Furthermore, a positive association has been reported between the duration of physical activity and greater mean annual increases in bone mineral density and bone thickness in children.

Declarations

Funding: This work received no specific funding from any public, commercial, or not-for-profit funding agency.

Conflicts of interest: The authors declare that they have no conflicts of interest.

Author contributions: G.N.: conceptualization and development of the topic, literature review, and preparation of the original draft. K.M.: data verification and editing, specialized contribution to exercise-related content and terminology, article structure and formatting, preparation of the abstracts, translation, and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

Ethical approval: Not required for this review of published literature.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process: OpenAI's ChatGPT was used during the writing of this scientific work solely for language editing, the correction of syntactic/grammatical errors, and the improvement of the flow of the text. All information, data and conclusions derive exclusively from the authors.

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