Plyometric exercise and bone health in children and adolescents: a systematic review.

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Abstract

Context: Many jumping interventions have been performed in children and adolescents in order to improve bone-related variables and thus, ensure a healthy bone development during these periods and later in life.

Objective: This systematic review aims to summarize and update present knowledge regarding the effects that jumping interventions may have on bone mass, structure and metabolism in order to ascertain the efficacy and perdurability of these interventions.

Data sources: A systematic review of articles using Medline-Pubmed and SportDiscus. Additional studies were identified by contacting clinical experts and searching bibliographies and abstract. Search terms included "bone and bones", "jump*", "Weight-bearing", "Resistance Training" and "school intervention".

Study selection: Only studies that had performed a specific jumping intervention in under 18-year olds and had measured bone mass were included.

Data extraction: Independent extraction of articles by 2 authors using predefined data fields.

Data synthesis: A total of 26 studies were included in this review. Most jumping interventions seemed to positively affect bone, as subjects included in the intervention groups showed higher bone mineral density, bone mineral content and bone structure improvements than controls. Moreover those studies that evaluated the perdurability of the effects found that some of the increases in the intervention groups were maintained after several years.

Conclusions: Jumping interventions during childhood and adolescence improve bone mineral content, density and structural properties without showing side effects. These type of interventions should be therefore implemented when possible in order to increase bone mass in childhood, which may have a direct preventive effect on bone diseases like osteoporosis later in life.

Introduction

Physical inactivity has a major health effect worldwide; in fact, it has been identified by the WHO as the fourth leading risk factor for global mortality causing an estimated 3.2 million deaths globally. Physical activity interacts as a protective factor versus several diseases, some of them related to bone such as osteopenia and osteoporosis. These are characterized by micro-deterioration of bone mass, and an increased risk of suffering a bone fracture[1]. Nevertheless, osteoporosis is a widespread disorder affecting millions of individuals of all ethnic backgrounds worldwide, particularly among older women. It is called “the silent thief” because it steals bone without any immediate consequence. Moreover, it is a growing disease which was estimated to increase in 2005 from 10 million to more than 14 in 2020 with an associated 25.3 billion dollars in costs in the USA[2].

There are some ways of counteracting osteoporosis and one of the most popular preventive treatments has been the optimisation of peak bone mass through childhood[3]. Peak bone mass, as the amount of bone present at the end of skeletal maturation, is an important determinant of osteoporotic fracture risk. The amount of bone mass gained during the 2 years of peak bone mineral accrual at adolescence approximates the quantity of bone lost in adulthood[4]. Several studies have shown that premenarche, even prepubertal (Tanner 1) vs. early pubertal (Tanner 2 and 3)[5-7], are times of greater bone response to exercise than postmenarche[8, 9]. It has been pointed out that an increase of only 3-5% in bone mineral density (BMD) is estimated to result in as much as 20-30% reduction in fracture risk[10]. Thus, childhood and adolescence are critical periods to intervene with lifestyle strategies that may prevent osteopenia- and osteoporosis-related fractures in the later years. Recent systematic reviews focusing on general weight-bearing activities during childhood and adolescence found that these activities provided a relevant method to significantly improve BMC[11] and BMD[12], although the effect sizes were small[11]. However, not all weight-bearing activities have the same peak-ground reaction forces, being the most osteogenics those that involve jumps and direction turns[13]. Running which is a weight-bearing sport entails around 2.6 vertical ground reaction forces while a drop jump entails around 5.5 vertical ground reaction forces. Therefore grouping these 2 weight-bearing activities together might mask the real effects that they independently have on bone mass.

As previously stated, one important strategy to increase peak bone mass is jumping and more specifically plyometric jump training. It involves a wide variety of exercises with different jumps and it has been associated with high ground reaction forces (four to seven times body weight) as defined by Hayes et al.[14]. Plyometric jump training is based on the premise that increasing eccentric preload on a muscle induces the myotatic stretch reflex and may cause a more forceful concentric contraction. This, taking into account the Mechanostat Theory will lead to stress and tension forces on the bones, which will make them adapt and therefore increase their strength[15]. Hind and Burrows[16] concluded that although weight-bearing exercise appeared to enhance bone mineral accrual in children, particularly during early puberty, it remained unclear as to what constituted the optimal exercise programme. To our knowledge plyometric jumps or exercise with jumps may be one of the best methods to improve bone mass due to the osteogenic stimulus, not only for the tensile forces applied by the muscles, but also for the impacts produced against the ground.

Therefore, the aim of this review is to summarize the available literature concerning jumping interventions and bone mass in children and adolescents in order to have a clearer picture on the effective interventions to bring new insight for building evidence-based osteogenic exercise programmes.

Methods

Data sources and search strategy

This study followed the systematic review methodology proposed in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement[17].

Identification of studies was performed by searching in the database MEDLINE- PubMed and SportDiscus. The search was conducted up to October 2014.

Three different types of search were conducted in order to find all the published studies. When possible, the filters of human, clinical trial and under-18 were applied for all searches. For the first search in MEDLINE the word jump* was combined with the thesaurus of “Bone and Bones” with the Boolean operator AND. For SportDiscus, the thesaurus of “BONE” and “JUMPING” were combined with the Boolean operator AND. The second search was performed by combining the thesaurus of “Weight-bearing” with “Resistance Training” with the Boolean operator OR. The results of this search were combined with “Bone and bone” with the Boolean operator AND. The third search was performed by combining “bone mineral density” with “school intervention” with the Boolean operator AND. Results of the searches are summarized in Figure 1.

Inclusion criteria

1) Types of study: Randomized and non-randomized controlled trials studying the effects of a jumping intervention on bone mass with or without coexistent treatments.

2) Types of participants: Children and adolescences without any pathology under 18 years old.

3) Types of intervention: Trials comparing the effects of an exercise-training program consisting of a plyometric or jumping intervention. No minimum duration or intensity was required.

4) Types of outcome measured: Bone mineral content (BMC) and/or BMD of total body (TB), lumbar spine (LS), limbs, hip (femoral neck (FN), trochanter (TR), inter-TR, proximal femur (PF) and Wards triangle subregions), bone architecture (from peripheral computed tomography (pQCT) or Magnetic Resonance Imaging (MRI) ultrasound parameters [Broadband Ultrasound Attenuation (BUA), Speed of sound (SOS) or Stiffness Index (STIF)] and bone markers.

Exclusion criteria

1) Studies in languages other than English or Spanish.

2) Unpublished data.

3) Studies with animals.

4) Studies without a control group (CON) that would allow comparison.

5) Studies focusing exclusively on bone metabolic markers and not using a bone imaging technique.

6) Studies not explaining the intervention program or only stating "A physical activity intervention".

7) Studies only adding an extra, non-specific physical activity class.

Search summary

Two independent researchers identified 3131 potentially relevant articles and 6 additional articles were identified through reference lists. Following review of titles and abstracts and excluding the duplicates the total was reduce to 51 potentially relevant papers for inclusion. Of these articles, 26 met the selection criteria and were included in this review (Figure 1).

Bias assessment

Studies were assessed using the "The Cochrane Collaboration's tool for assessing risk of bias in randomized trials"[18], (Table 2).

Results and Discussion

Table 1 summarizes studies concerning jumping interventions and bone mass in children and adolescences included in this review. Results have been organized according to the type of intervention performed by each study. This section has been divided into four subsections; BMC, BMD, Bone structure, and other factors affecting bone mass (calcium intake, pubertal status, training protocols and race).

BMC

The first study regarding a jumping intervention and BMC was developed by Morris et al.[19]. They studied the effects of a high-impact exercise program (step aerobics, bush dance and others) on bone mass assessed with Dual energy X-ray (DXA). After a 10-month intervention, premenarcheal girls allocated into the intervention group (INT) increased TB, LS, PF and FN BMC compared to those girls in the CON. Further on, two researches performed a step-aerobic program including drop jumps[9, 20]. Firstly, Heinonen et al.[9]. evaluated pre- and post-menarcheal girls during a 9-month intervention finding that those premenarcheal in the INT improved BMC more than CON at the LS and FN. However, those postmenarcheal showed no significant intergroup differences in any of the BMC parameters. Secondly, Kontulainen et al.[20] showed that BMC at the LS increased in a sample of fifty peri- and postpuberal females who trained twice per week for 9 months. During this period, 46% of the female participants become postpuberal, therefore the effect of maturation should have been controlled in this kind of studies.

Four studies performed drop jumps without a complementary step-aerobic program from several heights using boxes or steps. Witzke et al.[21] carried out an intervention with box depth jumps in adolescent girls (both pre- and postmenarcheal together) showing an improvement in BMC of the greater TR in the INT group. Fuchs et al.[22] reported gains in the INT BMC at FN and at LS with 100 two-footed jumps off 61-cm boxes three times per week during 7 months. One year later, Fuchs and Snow[23] re-evaluated their participants and noted that INT maintained greater FN BMC than CON. Johansen et al.[24] performed 5 days a week of 25 jumps from a 45-cm box showing that in 3 months, the INT gained more TB and Leg BMC than the CON. Gunters et al.[25], used higher boxes reaching 61-cm and trained three times per week. Prepubertal children of the INT group showed greater BMC improvements than the CON at LS, FN, TB and hip, being these improvements maintained 3 years after the intervention[25]. Anliker et al.[26] also performed a 2 day drop jumping intervention combined with other jumps during 9 months in children with attention deficit finding no differences in vBMC measured by pQCT between groups.

Therefore, it seems possible to state that drop jump interventions alone or combined with other jumping interventions, with 45-cm boxes or higher and during a minimum of 3 months seem to be enough to improve BMC at several bone sites.

Just one research showed no improvements using a drop jumping intervention combined with a rope skipping program[27]. Nevertheless, they pointed out that those girls who were not involved in previous sports activities improved BMC of the FN. Arnett and Lutz[28] also used a rope skipping intervention reporting that 10 minutes with a rate or 50 jumps per minute for 4 months was enough to increase BMC at the FN and at the greater TR more than CON.

Mackelvie et al. studied the effects of a 10-12-min circuit of jumping intervention in four different studies[6, 29-31]. The first one, focused on early pubertal girls showing that INT gained more BMC at the FN and in LS than CON after 7 months training 3 times per week[6]. Similar results were found for boys in the INT that gained more TB BMC[30]. Two years later, the same author continued with the intervention in both genders, finding on pubertal girls improvements in BMC at the LS and in FN after 20 months[29] and in prepubertal boys[31] greater increases in the FN for the INT than CON.

Several studies[32-37]carried out a jumping intervention with a variety of jumping activities such as skipping and hopping and other physical activities like running. Firstly, Specker et al.[36] performed an intervention with children aged 3 to 5 based on 20 minutes 5 days per week of hopping and skipping. They found that children in the INT showed higher increases in leg BMC than the CON. Similar results were found in pubertal and prepubertal children showing the INT group higher LS, FN, and TB BMC increases than the CON group[35], and these effects appeared to persist over three years[34]. Other researchers reduced from 5 to 3 days per week. They focused on hopping and skipping and still found benefits in the INT group. Children in the INT group showed higher improvements of femur and tibia BMC with a 8.5 month intervention [33]. Besides, improvements in femoral bone marrow adipose tissue volume were found with only 10 weeks of intervention [32]. Differently to the previous interventions Weeks et al.[37] developed a 2-day per week intervention for implementing their 10 minute jumping in school children. Children in the INT completed around 600 jumps per week improving TR, FN, LS and TB BMC values more than the CON.

Therefore, these interventions seem to be effective in pre- peri- and postpubertal children. Ten minutes twice a week might be enough to improve BMC, although it is possible that higher frequencies, volumes and protocol durations could produce a higher BMC and BMD improvement. Although the later is just a hypothesis as to our knowledge there are no studies comparing intervention protocols.

Several researchers[38, 39] used the Bounce at the Bell intervention, which required children to perform short bouts of high-impact jumping (counter-movement jumps) 3 times a day 5 days per week[39] which only entailed around three minutes per day. This type of intervention showed higher BMC improvements in FN and intertrochanteric region of those early pubertal children allocated in the INT[39]. When this intervention was combined with 15 extra minutes per day of specific jumping and running physical activity, boys in the INT had greater gains in LS and TB BMC than the CON[38].

BMD

The number of studies that did not measure BMD is surprising; as both, BMD and BMC are measured with the same device (i.e. DXA) future studies should include both measures in order to give more information of bone status.

Morris et al.[19] showed that females who were participating in a high impact exercise program (step aerobics, bush dance and others) improved TB, LS, PF and FN BMD and also LS bone mineral apparent density. Some years later, McKay et al.[5] studied the effects of a jumping intervention on prepubescent and early pubescent Asian and white children for 8 months showing that the INT had greater increase in femoral TR area BMD. Studies that found improvements in BMC with 10 minutes 5 days per week of hopping and skipping which have also been included in this review as a jumping intervention, also found improvements in TB and LS BMD[35]. Similar results were found when the intervention was reduced to 3 days per week in 10-year-old students[40]. Weeks et al.[37] proposed a 10-minute jumping intervention before class began, two days per week in school children and found that girls allocated to the INT increased LS BMD more than the CON.

A seven-month intervention with drop jumps 3 times per week from 10 to 20 minutes was performed by Petit et al.[7]. They divided their sample by maturity status and showed that in early-pubertal girls the INT had greater gains in FN and inter-TR BMD than CON. Fuchs et al.[22] in a similar program studied 45 prepubescent children showing that BMD at the LS increased more in the INT than in the CON.

In another study with early pubertal girls and with a circuit of jumping activities, MacKelvie et al.[6] observed that the INT improved areal BMD at the FN and LS and volumetric BMD (vBMD) at the FN. As occurred with BMC, the study carried out by Van Langednock et al.[27] found no differences in areal BMD when implementing drop jumps plus rope skipping.

When the "Bounce at the bell" intervention was performed, no differences were found for vBMD measured with pQCT between the intervention and the CON[41]. The other two studies[38, 39] that performed this type of intervention did not measure BMD.

Regarding perdurability of BMD gains after the intervention, Meyer et al.[34] found that the INT group in their study maintained higher TB BMD compared to the CON 3 years after the intervention.

In conclusion, most of the studies that performed a jumping intervention showed benefits in the INT for BMC at the TB[19, 24, 30, 35, 37], leg[24, 33, 36], FN[6, 9, 19, 22, 23, 28, 29, 31, 35, 37], PF[19, 27, 39], TR[21, 37], inter-TR[39] and LS[6, 9, 19, 20, 22, 29, 35, 37]. Only one study found that controls gained more TB BMC[39] while intervention children gained more BMC at the PF and intertochanteric region two relevant clinical sites. Two studies found no improvements in BMC with the intervention[26, 32], although the study performed by Casazza et al.[32] had a duration of only 10 weeks. Summarizing, regarding BMD, results were similar to those found in BMC, showing the INT improvements in the TB[19, 35] LS[19, 22, 35, 37], FN[7, 19, 40], PF[19, 27, 30], inter-TR[7] and femoral TR[5].

Therefore, it is possible to conclude that jumping interventions positively affect BMC and BMD. These increases in BMC and BMD due to ground impacts are in line with previous studies finding sports which entail high impacts more osteogenic[3], while other sports without impacts such as cycling[42] or swimming[43] do not produce the same effects. This is of extreme importance because bone optimization in childhood will result in stronger and denser bones in adulthood reducing the chances of developing osteoporosis later in life[44]. A 10 % increase of peak bone mass in childhood is estimated to reduce the risk of an osteoporotic fracture during adult life by 50 percent[45].

Similar results were found independently of the type of jumping intervention (i.e. drop jumps, circuit of jumping, skipping, hopping), we therefore encourage future researchers to perform enjoyable interventions with different exercises that vary along the programme in order to maintain motivation and avoid withdrawals.

In addition to bone health, improvements in other health-related fitness variables such as maximum oxygen uptake or body composition might also occur with these interventions[46]. This makes them highly recommended in primary schools.

A major question arising from this review, is what constitutes the optimal jumping programme to improve bone mass in children and adolescents. All intervention trials have achieved successful results independently of the exercise protocols such as: step aerobics, drop jumps, rope skipping, circuit interventions, and bounce at the bell. However, no quantitative, dose-response studies have been developed. Thus, it is difficult to ascertain what type and level of exercise program would be optimal to have a positive effect on bone mass. Results from the exercise interventions reviewed in this paper have varied. Yet comparison between studies is complex due to differences in design, control of variables duration of the intervention, the frequency at which exercises were performed and the ground reaction forces generated. It would be interesting that future studies compare different interventions instead of comparing an INT group to a CON group, in order to ascertain which type of intervention is more effective regarding bone mass.

Bone structure

pQCT was the most used technique to evaluate bone structure. Heinonen et al.[9] performed a combined step aerobic drop jumping intervention and assessed the tibial midshaft in pre- and postmenarcheral girls with pQCT. After 9 months of intervention no differences between groups (INT vs. CON) were found neither in pre- nor postmenarcheal groups. Similar results were found by Anliker et al.[26] when also performing a drop-jump intervention and Johansen et al.[24] that found no main effect of jumping on any of the pQCT tibia measurements. Other jumping interventions focused on hopping and skipping[36] did find greater periosteal and endoesteal circumferences gains in the INT group than the CON. Macdonald et al.[41] that performed the “Bounce at the bell” intervention found that the INT prepubertal boys increased bone stiffness index (BSI) more than CON.

Hip Structural Analysis (HSA), was also frequently used to evaluate bone structure. This program is used in PF DXA scans to evaluate bone geometry and estimate the hip structural strength. The INT that performed a circuit of jumping activities showed increases in structural parameters, such as subperiosteal and endosteal surfaces of the narrow neck region[31], and improvements in bone strength indexes such as the cross-sectional moment of intertia (CSMI)[31] and section modulus[31]. Petit et al.[7] performed a drop jumping intervention finding improvements in the section modulus (bending strength) at the FN in early pubertal girls. In contrast, no differences were found in these variables in prepuberal girls[7]. However, other studies using this technique showed no differences between INT and CON groups[39] with the previously mentioned bounce at the bell intervention.

Another technique to evaluate bone structure was quantitative ultrasound. After a rope skipping intervention during 4 months, the INT increased os calcis stiffness index[28] more than CON. Weeks et al.[37] performed a jumping intervention finding that the INT improved more than CON for broadband ultrasound attenuation which reflects bone strength, primarily as a function of bone mass[47].

One study[32] used MRI to assess bone health in children and found that those performing a 10-week intervention, presented a decrease in femoral marrow adipose tissue volume. This parameter has shown a reciprocal relationship with bone mineral preservation[48] and is therefore of great importance to bone mass.

Interventions evaluating bone with pQCT showed improvements in the INT groups at the tibia for vBMD[24, 26, 41] BMC[24, 26] periosteal and endosteal circumferences[36] and BSI[41]. Just a pair of studies showed no differences in structure bone parameters after the intervention using this device[9, 26].

Similar results were found with other measurement techniques, as studies using HSA[7, 31], Ultrasound[28, 37] or MRI[32] also found improvements in bone structure.

It seems clear that, independently of the used device to measure bone structure or bone strength, similar results can be found with higher improvements in structure and bone health in INT than in CON. This suggests that a jumping intervention might be beneficial to bone structure and strength, although these differences are not as large as those found in BMC and BMD.

No studies evaluating bone structure and strength studied the perdurability of the effects of the interventions. It is possible to hypothesize that these structural improvements are maintained longer in time than the improvements in BMC and BMD. Further researchers should focus on the perdurability of the benefits in bone structure and strength to corroborate this hypothesis.

Other factors affecting bone accretion

Calcium intake

Optimal exercise for promoting bone health is important, but it is also important to have an optimal dietary intake of nutrients and energy essential for normal growth processes and for bone metabolism[49, 50]. For this reason, some researchers combined interventions including jumps and calcium supplementation.

Specker et al.[36], included calcium as part of a jumping intervention, using daily chewable supplements, 5 days per week in 3- to 5- year-old children. Their study was composed by 4 groups; exercise and calcium group, exercise and placebo, non-exercise and calcium and non-exercise and placebo. They found that leg BMC increase was higher in children receiving calcium versus placebo, and that children in the exercise group had greater tibia periosteal and endosteal circumferences by pQCT at study completion. Moreover, in the exercise intervention group, those who received calcium had cortical thickness and cortical area larger than those who received placebo.

Iuliano-Burns et al.[33] and Ameri et al.[40] also found exercise-calcium interactions at the leg, more specifically at the femur. Burns et al.[33] suggested that calcium influenced bone mass at non-loaded sites while exercise, but not calcium increased bone mass at the loaded site.

Although studies combining plyometric intervention and calcium intake are scarce, it seems that a combination of exercise and calcium is more effective than consuming calcium or performing exercise alone. Other studies[51-53] including weight-bearing exercise and calcium combined together have found similar results, and future interventions searching to increase BMD or BMC should therefore take both variables into account.

Pubertal status

Several studies evaluated pubertal status in their participants, describing differences of the impact of the interventions on bone mass according to pubertal stage. Johannsen et al.[24], suggested that the greatest bone benefit from jumping was observed in pubertal children. Nevertheless, several other researchers [35, 41] suggested that the best stage for increasing bone structure was prepuberty.

Training protocols (time, duration, total minutes, g-forces).

As summarized in table 1, interventions varied from 10 weeks to 2 years, although most of them found similar results.

It seems that a 10 week intervention[32] might be enough to start producing changes in bone. However, these changes might not be reflected in BMD or BMC and therefore might not be detected with DXA. Although, such a short intervention does not change bone mass *per se*, it seems to decrease resident adipose tissue volume in the bone marrow which is reciprocally related to the amount of mineral in the long bones[48, 54] in adults, and has been suggested to be an independent predictor of fracture[54, 55].

Johansen et al.[24] extended in 2 weeks the previous training[32]. Children in their study performed 5 days a week of 25 jumps. Researchers found that in 3 months, the intervention group had gained more TB and leg BMC than the CON.

Compared to these short intervention studies, the longest intervention performed was that applied by MacKelvie et al.[31] that performed a 20 month intervention during 2 school years, and showed that intervention boys gained significantly more BMC at the femoral neck and greater bone area. Moreover, the intervention group increased CSMI and SM significantly more than the CON.

Most of the studies performed an 8 month intervention during a school year, and showed positive benefits in bone quantity[33, 37, 39] although, only one showed benefits in bone quality measured by QUS[37]. Longer interventions showed increases in both bone quantity[35, 36, 40] and quality[31, 36, 41].

It seems that as little as a 3-month intervention might begin to be beneficial to bone mass increasing BMC. However, longer interventions are needed in order to change bone structure and attain stronger bones, being the study that showed more differences between the INT and the CON groups a 2-year study that performed a 20-month intervention.

Most of the studies ranged from 8 to 12 months of intervention and found similar results, although a small amount evaluated the perdurability of the intervention. Fuch and Snow were the first to evaluate the perdurability after a 7-month intervention finding that INT maintained 4% greater FN BMC than CON after 14 months[23]. Meyer et al.[34] also evaluated bone mass 3 years after finding that children that had performed the 9-month intervention showed higher differences at follow-up for TB BMD compared to controls and higher TB, FN and total hip BMC.

The lack of studies evaluating perdurability of shorter interventions[28, 32] disallow comparisons regarding if longer interventions are better in the longer term. If both interventions were equally effective as a practical purpose, the shorter one should be performed. Nevertheless, if a longer intervention has a longer perdurability it would be appropriate to perform them. It can be suggested that future randomized controlled trials study as well the perdurability of the effect, to describe bone health after ending the intervention. If possible, it would be interesting that recently published studies[32, 40] also perform a follow-up in order to describe this perdurability.

Race

To our knowledge, only two studies evaluated the differences in bone variables after a jumping intervention regarding ethnicity [5, 30] finding different results. Mackelvie et al.[30] compared Asian boys to white boys, showing no differences in the bone accrual response to exercise over 7 months at any measured site. However, Mckay[5] et al. found a greater increase in TB BMD in Asian children when compared to white children for a similar training program. These differences between studies might be attributed to the different age range between the two samples.

Limitations

Although most studies reported positive skeletal effects in those exercising, several confounders, limitations and considerations were evident. These are mainly concerning to selection procedures, compliance rate and control of variables. Regarding the later, calcium intake was rarely registered and is an important variable regarding bone mass that should have been controlled throughout the intervention period.

Also a possible publication bias might exist, as it has been found that trials with positive findings are published more often, and more quickly, than trials with negative findings[56, 57].

Conclusion

Although the exact amount of volume, intensity and duration needed for jumping interventions to be effective are unclear, jumping interventions during childhood and adolescence improve bone health parameters, from BMC, BMD to structure and size without showing side effects. Moreover, these effects are maintained in time after the intervention has ended. These interventions should be therefore implemented, when possible, as this may have a direct preventive effect on bone diseases like osteoporosis later in life.

The bone structure and strength improvements in addition to BMC and BMD improvements underline the importance that specific training programmes have on bone health. These reported improvements in bone mass in addition to other non-studied improvements in fitness related variables should make these interventions compulsory along the students' life. Jumping interventions in the middle of the class duration in each session could improve fitness related variables and attention as several studies have demonstrated that the student attention only lasts for 20 minutes[58], with Europe classes lasting an average of 50 minutes. Therefore, by performing 20 jumps in the middle of the class duration in each session students would perform around 120 jumps per day, 2500 per month, improving at least bone mass, fitness related variables and attention with a possible increase in school performance[59].

Future studies should compare interventions to try to determine which is the best intervention regarding volume, intensity and duration to improve bone mass, as it still remains unclear what type and doses of jumping intervention is best to improve bone mass. In addition, if possible, studies that have already performed perdurability follow-ups should perform future follow-ups when children reach their peak bone mass ages (between 25 and 30 years), in order to describe if those that performed the intervention reached a higher peak bone mass than those allocated in the control group.

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Figure 1. Flowchart diagram of the included studies.

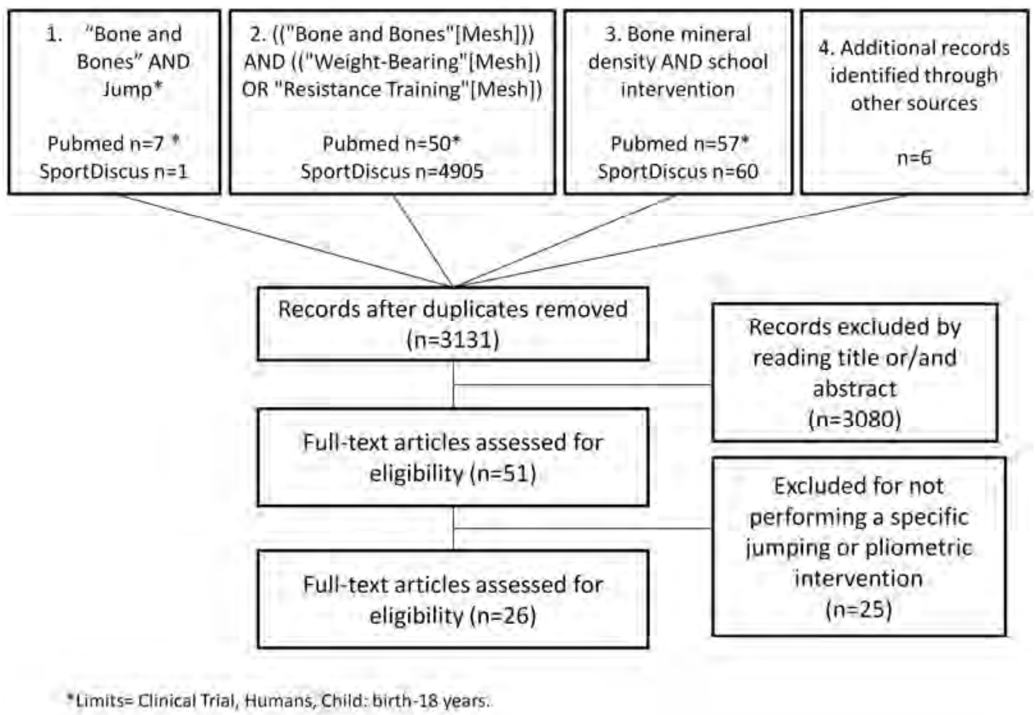

Table 1. Studies concerning jumping interventions and bone mass in children and adolescences

Authors	Participants	N	Sex	Age (mean±SD or range)	Protocol							Device	Variables	Measures	Outcomes
					Type	Time	Exercises	Duration	Frequency	Tot. min	g forces				
Morris et al. 1997[19]	Premenarcheal girls	71 38 INT 33 CON	F	9-10	Step-aerobic	30 min	Step aerobics, bush dance, skipping, modern dance and others*	10 months	3 times per week	3870	-	DXA	BMC BMD BMAD	TB LS PF FN	INT showed higher BMD ↑ for TB, LS, PF and FN than CON INT showed higher BMC ↑ for TB, LS, PF, FN and LS BMAD than CON
McKay et al. 2000[5]	Prepubescent and early pubescent Asian and white children	63 INT 81 CON	M-F	6.9-10.2	Jumping intervention	10-30 min	10 tuck jumps and Jumping, hopping, and skipping	8 months	3 times weekly and twice weekly into physical education classes	1700-5100	3-5 times BW	DXA	aBMD	TB LS PF	INT showed higher ↑ in femoral trochanteric aBMD than CON
Heinonen et al. 2000[9]	Pre- and postmenarcheal girls	64 INT 25 pre 39 post 62 CON 33 pre 29 post	F	10-15	Step-aerobic + drop jump	20 min jump training	Step-aerobic program with additional jumps (from 100 to 150 both-leg jumps and box jumps)	9 months	2 sessions per week	1560	-	DXA p-QCT	BMC COD CSA BSI	LS PF Tibal midshaft	In the premenarcheal girls, the INT showed higher BMC ↑ at the LS and FN than CON

Witzke et al. 2000[21]	Adolescent girls	25 INT 28 CON	F	14.6±0.5	Drop jumps	30-45 min	Hopping, jumping bounding and box depth jumps (from 100-140 jumps at the beginning to 360-1000 jumps at the end)	9 months	3 times per week	3510-5265	4-7 times BW	DXA	BMC	TB PF LS Femoral mid-shaft	INT showed higher BMC ↑ at the greater TR than CON
Petit et al. 2002 [7]	Pre- and early-pubertal girls	Prepubertal 43 INT 25 CON Early-pubertal 43 INT 63 CON	F	9-12	Drop jumps	10-12 min	From 10 to 20 jumps and the height from 10 to 50 cm. 50 times at each initial session and 100 jumps by the end of each level	7 months	3 times per week	900-1080	3.5-5 times BW	DXA HSA	BMD Subperiosteal width CSA CSMI	Hip	In early-pubertal girls the INT showed higher BMD ↑ at the FN and inter-TR than CON INT showed higher structural changes for SM (bending strength) at the FN than CON
MacKelvie et al. 2001[6]	Early pubertal girls	87 INT 90 CON	F	8.7-11.7	Circuit of jumping activities	10-12 min	From 50 to 100 jumps each session	7 months	3 times per week	900-1080	3.5-5 times BW	DXA	BMC aBMD	TB LS PF FN TR	Early pubertal girls in the INT gained more bone at FN and LS than early pubertal girls in the CON.
Fuchs et al. 2001 [22]	Prepubescent children	45 INT 25 Boys 20 Girls 44 CON 26 Boys 18 Girls	M-F	5.9-9.8	Drop jumps	20 min	100, two-footed jumps off 61-cm boxes each session	7 months	3 times per week	1800	8.8 times BW	DXA	BMC BMD	Hip LS	INT showed higher BMC ↑ at the FN and LS than CON INT showed higher BMD ↑ at the LS than CON

Mackelvie et al. 2002[30]	Prepubertal boys	61 INT 60 CON	M	10.3±0.7 10.2±0.6	Circuit of jumping activities	10-12 min	From 50 to 100 jumps each session	7 months	3 times per week	900-1080	3.5-5 times BW	DXA	BMC aBMD	TB LS PF FN TR	INT showed higher BMC ↑ for the TB than CON INT showed higher aBMD ↑ for the PF than CON
Arnett and Lutz 2002[28]	Pospubescent girls	13 INT high volume 12 INT low volume 12 CON	F	14.7±0.7	Rope skipping	10 or 5 min each INT group	A rate of 50 jumps per min	4 months	4 times per week	340-680	3.2±0.2 times BW	DXA QUS	BUA SOS BMC	LS PF	High-volume INT showed higher ↑ for STIF, and BMC at the FN and greater TR than CON
Fuchs and snow 2002[23]	-	37 INT 37 CON	M-F	8.8±0.1	Drop jumps	-	-	7 months	-	-	-	DXA	BMC	PF LS	INT maintained 4% greater FN BMC
Kontulainen et al. 2002[20]	-	50 INT 49 CON	F	12.5±1.5	Step-aerobic + drop jump	50 min	Step-aerobics sessions with additional jumps (150 both-leg and 50 one-leg box (30 cm high) jumps	9 months	2 sessions per week	3900	-	DXA	BMC	LS PF	INT showed higher BMC ↑ in the LS than CON
MacKelvie et al. 2003[29]	Pubertal girls	32 INT 43 CON	F	9.9±0.6 10.3±0.4	Circuit of jumping activities	10 min	Plyometric, alternating-foot and 2-foot obstacle jumps from 5 laps (55 jumps) to 12 (132 jumps)	20 months	3 times per week	2580	3.5-5 times BW	DXA	BMC	TB LS PF	INT showed higher BMC ↑ at the LS and FN than CON

Van Langendonck et al. 2003[27]	Prepubertal monozygotic female twins	21 INT 21 CON	F	8.7±0.7	Drop jumps + rope skipping	10 min	Rope skipping 50 times, hopping 20 times, jumping from a wooden box of 40 cm high landing on both feet 30 times	9 months	3 times per week	1170	3.5-5 times BW	DXA	BMC aBMD	PF FN LS	No differences in bone indexes between groups but girls who were not involved in previous sport activities improved aBMD and BMC of the PF more than CON
Johansen et al. 2003[24]	Children	26 INT 26 CON	M-F	10.3±5.3 10.0±5.1	Drop jumps	No time limit	25 jumps day from a 45-cm box	12 weeks	5 days per week	650	4-5 times BW	DXA pQCT	BMC PERIC ENDC COA CTH	TB, LS, FN 4 and 20% distal tibia	Jumpers showed higher BMC ↑ for TB and leg than CON. There was no main effect of jumping on any pQCT tibia measurements. During peripubertal stage INT showed higher BMC ↑ at LS and 4% distal tibia than CON

Specker et al. 2003[36]	3 to 5 year-old children	124 INT exercise 114 CON	M-F	3.9±0.6 3.8±0.5 4.0±0.6 4.0±0.6	Jumping intervention	30 min	Groups 1 and 2, jumping, hopping and skipping activities	12 months	5 days per week	7800	-	DXA pQCT	BMC BA PER END COA CTH	TB, Arm, Leg, 20% distal tibia	Exercise-INT showed higher periosteal and endosteal circumference ↑ than children in the fine motor group. In the CA-INT those that were in the exercise-INT showed higher ↑ for CTH and COA than those receiving placebo. In the placebo-INT those that were in the exercise-INT CTH and COA were smaller than those in the without the exercise intervention. Leg BMC ↑ more in the CA than the placebo groups

Iualiano-Burns et al. 2003[33]	Pre and early-pubertal girls	34 INT exercise 32 CON	F	8.7±0.3 9.0±0.2 8.8±0.3 8.9±0.3	Jumping intervention	20 min	Groups 1 and 2 hopping, jumping and skipping + 2 g milk minerals (400 mg of calcium) Groups 3 and 4 streching and low-impact dance routines	8.5 months	3 days per week	2220	2-4 times BW	DXA	BMC	TB, LS	An exercise-calcium interaction was detected at the femur Exercise but not calcium, increased bone mass at the tibia. INT showed higher BMC ↑ than CON BMC ↑ 2-4% more in the calcium supplemented than the non-supplemented groups at the radius-ulna
MacKelvie et al. 2004[31]	Prepubertal boys	31 INT 33 CON	M	10.2±0.5 10.1±0.5	Circuit of jumping activities	10-12 min	50 to 100 jumps per session across three levels of difficulty. Exercise stations incorporated plyometric jumps, alternating-foot jumps and 2-ft obstacle jumps.	20 months	3 days per week	2610	3.5-5 times BW	DXA HSA	BMC BA CSMI CSA SM CTH, END PER	TB, LS, PF, FN, TR,	INT boys showed higher BMC ↑ at the FN than CON INT boys showed higher CSMI and SM ↑ than CON

Mckay et al. 2005[39]	Early pubertal children	51 INT 71 CON	M-F	10.1±0.5 10.2±0.4	Bounce at the bell	3 min	10 countermovement jumps three times each school day	8 months	5 days per week	510	5 times BW	DXA HSA	BMC BA CSA CSM SM	TB, LS, PF, FN, TR, IT,	INT showed higher BMC ↑ at the PF and IT than CON CON showed higher BMC ↑ for adjusted than INT No significant differences between INT and CON for bone structural variables
Mcdonald et al. 2007[41]	School children	281 INT 129 CON	M-F	10.2±0.6	Bounce at the bell	15 min 3 min	1.(Skipping, dancing, playground circuits, and simple resistance exercises with exercise bands) 2. Jumps	16 months	5 days per week 4 days per week	6000	5 times BW	pQCT	BSI SSIPOL TOA COD CSA SM vBMD	8 & 50% of the tibia,	Intervention prepubertal boys showed higher BSI ↑ than CON
Gunter et al. 2008[25]	School children	101 INT 104 CON	M-F	8.6±0.8	Drop Jumps	10 min	90-100 jumps	7 months	3 days per week	900	3-4 times WB	DXA	BMC	TB Hip FN LS	INT showed higher BMC ↑ than CON at the LS, hip, FN and TB. Even three years after the intervention
Macdonald et al. 2008[38]	School children	293 INT 117 CON Asian 53% Caucasian 35% Other ethnics 12%	M-F	9-11	Bounce at the bell	-	From 5 to 36 two-foot landing jumps	11 months	3 times per day 4 days per week	-	-	HSA DXA	BMC BA CSA CSM SM	FN PF LS TB	INT boys showed higher BMC ↑ at the LS and TB than CON.

Weeks et al. 2008[37]	School children	52 INT 47 CON	M-F	13.8±0.4	Jumping intervention	10 min	Jumps, hips, tuck-jumps, jump-squats, stride jumps, star jumps, lunges, side lunges and skipping	8 months	2 days per week	680	-	DXA QUS	BMC BMD BA BMAD CTH CSMI BSI BUA	FN, TR, LS TB, Calcaneus Vertical jump test	INT showed higher calcaneal BUA ↑ than CON INT showed higher BMC FN,TR, LS and TB ↑ than CON INT boys showed higher WB BMC ↑than CON boys INT boys showed ↑ for calcaneal BUA and FN area while CON did not. INT girls ↑ FN BMC and LS BMAD while CON did not. In the INT improvements in TR, LS and WB BMC were greater in boys than girls.

Meyer et al. 2011[35]	School children	158 INT 133 CON	M-F	6-7 & 11-12 6-7 & 11-12	Jumping intervention	45 min	At least 10 min of jumping activities like hopping, jumping up and down stairs, rope skipping etc. 3-5 short activity breaks during academic lessons, comprising motor skill tasks such as jumping or balancing every day. 10 min PA homework	One school year (9 months)	2 days per week	3510	-	DXA	BMC BMD	TB, FN, LS	INT showed larger ↑ in TB BMC from baseline INT showed higher BMC ↑ at FN and LS than CON A larger intervention effect in prepubertal than pubertal children was found.
Ameri et al. 2012[40]	Students with attention deficit	28 INT exercise 26 CON	M	INT+CA 10.3±2.0 INT+PL 10.3±2.1 CON+CA 10.2±2.1 CON+PL 10.4±2.2	Jumping intervention	50 min	Walking, running, jumping, hippinng and galloping	9 months	3 days per week	5850	-	DXA	BMD	FN	BMD improvement was significant in all experimental groups INT+CA had significantly greater changes in FN BMD than other groups

Anliker et al. 2012[26]	Children	22 INT 23 CON	M-F	10.5±1.2 10.8±1.1	Drop jumps	10 min	Two-and one-legged hopping, drop jumps, side to side jumps, jumping jacks, jumps and landings from a podium, jumps over barriers and short multidirectional sprints	8 months	2 days per week	720	3-3.5 times BW	pQCT	vBMC, trvBMD COD vBMD trBOA COA Peri Endo SSIPOL	Tibia	There were no significantly different adaptations in bone strength and geometry between the two groups from pre to post intervention.
Casazza et al. 2012[32]	Young Children	10 INT 10 CON	M	4.8±0.2 5.1±0.1	Jumping intervention	10 min 10 min 10 min	Jumping Hopping Running	10 weeks	3 days per week	900		DXA MRI	BMC BMAT CTH	TB, Femur	INT showed a higher decrease in femoral BMAT than CON No changes in either femoral cortical bone volume or TB BMC in both groups.
Meyer et al. 2013[34]	School children	149 INT 65 CON	M-F	8.8±2.1 8.8±2.2	Jumping intervention	45 min	At least 10 min of jumping activities like hopping, jumping up and down stairs, rope skipping etc. 3-5 short activity breaks during academic lessons. 10 min PA homework	One school year (9 months)	2 days per week	3510	-	DXA	BMC BMD	TB, FN, LS	INT showed significantly higher BMC ↑ for WB, FN and THIP compared to CON INT showed higher adjusted ↑ for WB BMD compared to CON

↑=Increases; aBMD = areal BMD; BA = Bone area; BMAD = Bone Mineral Apparent Density; BMAT = Bone marrow adipose tissue; BMC = Bone Mineral Content; BMD = Bone Mineral Density; BSI = Bone Strength Index; BSI=Bone strength index; BSI=Bone strength index; BUA = Broadband Ultrasound Attenuation; BW = Body Weight; CA = Calcium Intervention; COA = Cortical Area; COD = Cortical Density; CON = Control group; CSA = Cross-Sectional Area; CSMI=Cross-sectional moment of inertia; CTH = Cortica thickness; DXA = Dual Energy X-ray; END = Endosteal width; ENDC = Endosteal circumference; Ex=Exercise intervention; F = Females; FN = Femoral Neck;

HAS = Hip Structural Analysis; IBS=Index of bone structural strength; INT = Intervention group; IT = Intertrochanteric region; LS = Lumbar Spine; M = Males; PER = Periosteal width; PERIC = Periosteal circumference; PF = Proximal Femur; PL=Placebo; p-QCT = peripheral Quantitative Computed Tomography; QUS = Quantitative UltraSound; SM = Section Modulus; SOS = Speed of Sound; SSI=Polar strength strain index; SSIPOL = Strength Strain Index; STIF = Stiffness Index; TB = Total Body; THIP=Total hip; TOA = Total area; TR = Trochanter; trbBMD = Trabecular vBMD; trBOA=Trabecular BA; vBMC = Volumetric BMC; vBMD = Volumetric BMD.

Table 2. The Cochrane tool for assessing risk in randomized trials.

Author	Random sequence generation	Allocation concealment	Blinding of participants	Blinding of personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Morris et al. 1997 [19]	High risk	Unclear risk	High risk	Low risk	High risk	Low risk	Low risk	
McKay et al. 2000 [5]	Unclear risk	Unclear risk	Unclear risk	Unclear risk	High risk	Low risk	Low risk	A greater increase in height in the control group versus the exercise group
Heinonen et al. 2000 [9]	High risk	Unclear risk	High risk	Unclear risk	High risk	Low risk	Low risk	
Witzke et al. 2000 [21]	High risk	Unclear risk	High risk	Unclear risk	High risk	Low risk	Low risk	
Petit et al. 2002 [7]	Unclear risk	Unclear risk	Unclear risk	Unclear risk	High risk	Low risk	Low risk	
MacKelvie et al. 2001 [6]	Unclear risk	Unclear risk	Unclear risk	Unclear risk	High risk	Low risk	Low risk	
Fuchs et al. 2001 [22]	Low risk	Unclear risk	High risk	Unclear risk	High risk	Low risk	Low risk	
Arnett and Lutz 2002 [28]	Low risk	Unclear risk	High risk	Low risk	High risk	Low risk	Low risk	
Fuchs and snow 2002 [23]	Low risk	Unclear risk	High risk	Unclear risk	High risk	Low risk	Low risk	
Kontulainen et al. 2002 [20]	High risk	Unclear risk	High risk	Unclear risk	High risk	Low risk	Low risk	
MacKelvie et al. 2002[30]	Unclear risk	Unclear risk	Unclear risk	Unclear risk	High risk	Low risk	Low risk	
MacKelvie et al. 2003 [29]	Unclear risk	Unclear risk	Unclear risk	Unclear risk	High risk	Low risk	Low risk	
Van Langendonck et al. 2003 [27]	Low risk	Unclear risk	High risk	Low risk	High risk	Low risk	Low risk	
Johannsen et al. 2003 [24]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Specker et al. 2003 [36]	Low risk	Unclear risk	Low risk*	High risk	High risk	Low risk	Low risk	
Iuliano Burns et al.2003 [33]	Low risk	Unclear risk	Low risk*	High risk	High risk	Low risk	Low risk	
Mackelvie et al. 2004 [31]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Mckay et al. 2005 [39]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Macdonald et al. 2007 [41]	Low risk	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	
Gunter et al. 2008 [25]	Unclear	Unclear risk	High risk	Low risk	High risk	Low risk	Low risk	
Macdonadl et al. 2008[38]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Weeks et al. 2008 [37]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Meyer et al. 2011 [35]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Ameri et al.2012 [40]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	
Anliker et al. 2012 [26]	Low risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	

Casazza et al. 2012 [32]	High risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk

*Two types of exercise, and regarding calcium intake there is a placebo group.