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

Alejandro Gómez-Bruton, Ángel Matute-Llorente, Alejandro González-Agüero, José A. Casajús, Germán Vicente-Rodríguez

Zaragoza, Spain

Review article

Background: **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. 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 durability (duration of the effects caused by the intervention) of the interventions.**

Data sources: **Identification of studies was performed by searching in the database MEDLINE/PubMed and SportDiscus. Additional studies were identified by contacting clinical experts and searching bibliographies and abstracts. Search terms included "bone and bones", "jump*", "weight-bearing", "resistance training" and "school intervention". The search was conducted up to October 2014. Only studies that had performed a specific jumping intervention in under 18-year olds and had measured bone mass were included. Independent extraction of articles was done by 2 authors using predefined data fields.**

Results: **A total of 26 studies were included in this review. Twenty-four studies found positive results as subjects included in the intervention groups showed higher bone mineral density, bone mineral content and bone structure improvements than controls. Only two studies found no effects on bone mass after a 10-week and 9-month intervention. Moreover, those studies that evaluated the durability 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 side effects. These type of interventions should be therefore implemented when possible in order to increase bone mass in early stages of life, which may have a direct preventive effect on bone diseases like osteoporosis later in life.**

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Introduction

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] Moreover, Osteoporosis is a growing disease which was estimated to increase from 10 million in 2005 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] In boys, the

Author Affiliations: Growth, Exercise, Nutrition and Development (GENUD) Research Group, University of Zaragoza, Zaragoza, Spain (Gómez-Bruton A, Matute-Llorente A, González-Agüero A, Casajús JA, Vicente-Rodriguez G); Faculty of Health and Sport Sciences (FCSD), Department of Physiatry and Nursing, University of Zaragoza, Ronda Misericordia 5, 22001-Huesca, Spain (Gómez-Bruton A, Matute-Llorente A, Casajús JA, Vicente-Rodriguez G)

Corresponding Author: Germán Vicente-Rodriguez, PhD, Growth, Exercise, Nutrition and Development (GENUD) Research Group, Faculty of Health and Sport Sciences, University of Zaragoza, Grupo GENUD Edificio SAI 2ª planta, Zaragoza, Spain (Tel: +34 876553754 or 976761000 ext. 843754; Fax: +34 974238422/+34 974239384; Email: gervicen@unizar.es)

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corresponding maturational stage would be 12-14 years, but more studies are needed in prepubertal, early pubertal, and pubertal boys to substantiate this.[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 bone mineral content (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 that involve jumps and direction turns.[13]

As previously stated, one important strategy to increase peak bone mass is jumping and more specifically plyometric jump training which entails fast, powerful movements in which a muscle is loaded and contracted in a rapid sequence. There is a muscle-tendon component in this type of training as the muscle is lengthened while loaded (eccentric contraction) just prior to the contraction, producing greater force through the storage of elastic energy. The quick transition from the eccentric to the concentric phase is known as the stretch shortening cycle and is one of the underlying mechanisms of plyometric training. In addition, there is also a neurological component, as the stretch shortening cycle affects the sensory response of the Golgi tendon organs making them less likely to send signals to limit force production facilitating greater contraction forces than normal strength or power exercises. This type of training 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 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 the tensile forces applied by the muscles, but also 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, children and adolescents were applied for all searches. For the first search in MEDLINE the word jump* was combined with the MeSH "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 bones" 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 Fig..

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: 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)

Review article

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; 7) Studies only adding an extra non-specific physical activity class or only stating "a physical activity intervention" or "an extra 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 reduced to 51 potentially relevant papers for inclusion. Of these articles, 26 met the selection criteria and were included in this review (Fig.).

Studies were assessed using the "The Cochrane Collaboration's tool for assessing risk of bias in randomized trials" (Supplemental Table 3).[18]

Results and Discussion

Supplemental Tables 1 and 2 summarize studies regarding jumping interventions and bone mass in children and adolescents 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).

Bone mineral content

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 absorptiometry (DXA). After a 10-month intervention, premenarcheal girls allocated into the intervention group (INT) showed increased TB, LS, PF and FN BMC compared with those girls in the CON. Further on, two researches performed a step-aerobic program including drop jumps.[8,20] Heinonen et al[8] evaluated pre- and post- menarcheal girls during a nine-month intervention finding that those premenarcheal in the INT improved BMC more than the CON at the LS and FN. However, those postmenarcheal showed no significant intergroup differences in any of the BMC parameters. Kontulainen et al[20] showed that BMC at the LS increased in a sample of fifty early and pubertal females who trained twice per week for nine months. During this period, 46% of the female participants reached puberty, 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 seven months. One year later, Fuchs and Snow[23] re-evaluated their participants and noted that INT maintained greater FN BMC than CON. Johannsen et al[24] performed five days a week of 25 jumps from a 45-cm box showing that in three months, the INT gained more TB and leg BMC than the CON. Gunter 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 three years after the intervention.[25] Anliker et al[26] also performed a two-day drop jumping intervention combined with

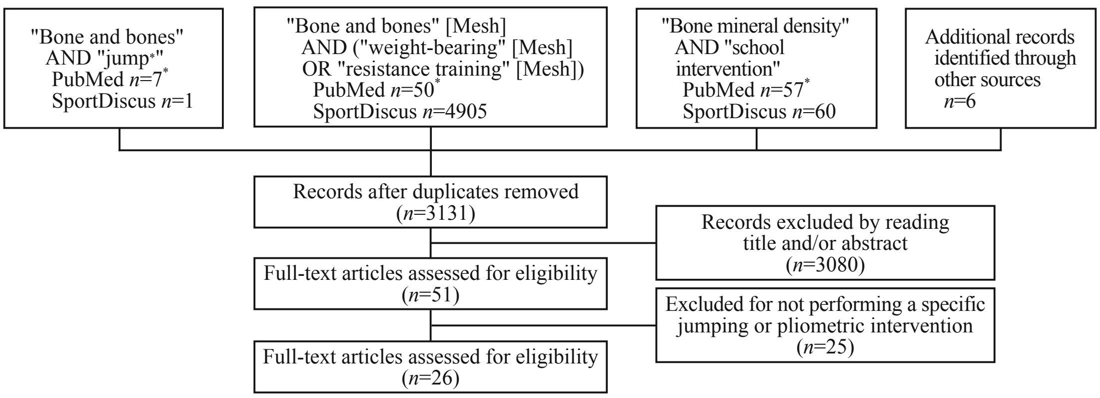

Fig. Flowchart diagram of the included studies. *: Limits to "Clinical Trial, Humans, Child: birth-18 years".

other jumps during nine months in children with attention deficit finding no differences in volumetric 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 three 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 four months was enough to increase BMC at the FN and at the greater TR more than CON.

Mackelvie et al[5,29-31] studied the effects of a 10-12-min circuit of jumping intervention in four different studies. The first one, focused on early pubertal girls showing that INT gained more BMC at the FN and LS than CON after seven months of training three times per week.[5] 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 the 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 lunges, side lunges and running. Specker et al[36] performed an intervention with children aged 3 to 5 based on 20 minutes five days per week of hopping and skipping finding that children in the INT showed higher increases in leg BMC than the CON. Similar results were found in pre- and pubertalpubertal 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 two-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-, early-, and pubertal 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 higher BMC and BMD improvements. 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) three times a day five 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 for 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]

Bone mineral density

The number of studies that did not report BMD values are surprising. Nevertheless, BMC is considered the preferred method of assessment for bone status in paediatric population because of its reproducibility, and lack of areal density-related errors.[40]

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[6] studied the effects of a jumping intervention on prepubertal and early pubertal 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 five 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 three days per week in 10-year-old students.[41] 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 three 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] found 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[5] observed that INT improved areal BMD at the FN and LS and volumetric BMD (vBMD) at the FN. As occurred with

BMC, Van Langendonck 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 tibia vBMD measured with pQCT between the intervention and the CON.[42] The other two studies[38,39] that performed this type of intervention did not measure BMD.

Regarding durability 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 three 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,[5,8,19,22,23,28,29,31,35,37] PF,[19,27,39] TR,[21,37] inter-TR[39] and LS.[5,8,19,20,22,29,35,37] 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] was performed in 3 to 6 year old children in which biological changes in BMC might overcome those imposed by an intervention 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,[7,19,41] PF,[19,27,30] inter-TR[7] and femoral TR.[6]

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%.[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.

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 and strength indexes

Supplemental Table 2 summarizes bone structure and strength indexes. pQCT was the most used technique to evaluate bone structure. Nevertheless, this assessment device presents multiple outcome measures. There is no consensus as to which are the best sites to measure bone structure and the choice depends on whether it is a metaphyseal (trabecular bone) or diaphyseal (cortical bone) measurement. Therefore, each author selects a percentage of the total length of the measured limb or a fixed distance from the growth plate. This lack of consensus, disallows a clear comparison among studies. Heinonen et al[8] performed a combined step aerobic drop jumping intervention and assessed the tibial midshaft (located at the 50% of the bone length) in pre- and postmenarcheral girls with pQCT. After 9 months of intervention, no differences were found for cortical density, cortical area nor polar section modulus between the intervention and control groups neither in pre- nor postmenarcheal groups. Similar results were found by Anliker et al[26] (measurements performed at the 4%, 14%, 38% and 66% of total tibial length) when also performing a drop-jump intervention and Johannsen et al[24] (measured at 4% and 20% of total tibial length) 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 (20% of total tibial length) in the INT group than the CON. Macdonald et al[46] (measurements at the 8% and 50% of total tibial length) 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) and section modulus.[31] The section modulus (Z), a determinant of bending strength, is computed as Z=CSMI/(maximum distance from centre of mass to outer cortical margin), and is calculated from the HSA analyses of the femoral neck scan. Petit et al[7] performed a drop jumping intervention finding improvements in the section modulus 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 the 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[24,26,42] BMC[24,26] periosteal and endosteal circumferences[36] and BSI.[42] Just a pair of studies showed no differences in bone structure parameters after the intervention using this device.[8,26]

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 the INT than in the 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 durability 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 durability 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, five 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 Arab Ameri et al[41] also found exercise-calcium interactions at the leg, more specifically at the femur. Iuliano-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 on bone mass according to intervention and pubertal stage. Johannsen et al[24], suggested that the greatest bone structure benefits from jumping interventions was observed in puberty. Nevertheless, several other researchers[35,42] suggested that the best stage for increasing bone structure was prepuberty. It therefore seems that the 2 studies performed with pQCT[24,42], presented contradictory results regarding the best period in which to perform a jumping intervention. Both Johannsen et al,[24] and Macdonald et al[46] found positive effects in all children included in their studies (pre-pubertal and pubertal), suggesting that jumping interventions may provide bone structure improvements in both stages. Several aspects could be influencing these results, such as differences in the positioning line where the pQCT performs the scan, as Macdonald et al[46] placed it at 4% from the reference line to determine trabecular values while Johannsen et al[24] placed it at the 8% from the reference line. In addition, the positive interaction found by Macdonald et al[46] sustaining the conclusion that the jumping intervention was better in prepubertal stages rather than early pubertal stage was only found for a calculated bone strength index, while there was no interactions for any of the measured variables such as total density and total area. The lack of further studies evaluating the effect of jumping at different maturation stages disables a clear conclusion. It therefore seems extremely important to perform new studies implement the same intervention in pre-, early-, and pubertal children in order to determine which maturation-group shows a higher improvement due to the intervention.

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

As summarized in Supplemental Tables 1 and 2, interventions varied from 10 weeks to two 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]

Johannsen et al[24] extended in two weeks the previous training.[32] Children in their study performed five days a week of 25 jumps. Researchers found that in three 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 two 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 quantitative ultrasound.[37] Longer interventions showed increases in both bone quantity[35,36,41] and quality.[31,36,42]

It seems that as little as a three-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 two-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 durability of the intervention. Fuch and Snow were the first to evaluate the durability after a seven-month intervention finding that INT maintained 4% greater FN BMC than CON after 14 months.[23] Meyer et al[34] also evaluated bone mass three years after finding that children under nine-month intervention had higher TB, FN and total hip BMC at follow-up for TB BMD compared to the controls.

The lack of studies evaluating durability 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 had a longer durability it would be appropriate to perform them. It can be suggested that future randomized controlled trials study as well the durability of the effect, to describe bone health after ending the intervention. If possible, it would be interesting that recently published studies[32,41] also perform a follow-up in order to describe this durability.

Race

To our knowledge, only two studies evaluated the differences in bone variables after a jumping intervention regarding ethnicity[6,30] 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 et al[6] 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. Moreover, not all studies that use DXA to assess BMD, evaluate change in height between pre and post-evaluations. This is of critical relevance as DXA is a two dimensional tool and therefore, is only able to assess length and width of the scanned bone, but not its depth. Because depth is not seen, a bone with greater depth will attenuate more photons and will be reported as being more dense, which might not necessary be the case, as the amount of bone might have increased linearly with bone growth remaining the volumetric BMD constant. It therefore seems extremely important to adjust the results by change in height or by other similar covariables that might influence results.

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]

Conclusions

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, such as BMC, BMD and bone structure without showing side effects. Moreover, these effects are maintained in time after the intervention has ended. These interventions should be therefore implemented in healthy children, when possible, as this may have a direct preventive effect on bone diseases like osteoporosis later in life. In addition, if positive results are found in healthy children, it is possible that similar results would be found in disabled populations, as other similar interventions have showed bone improvements with other types of training.[58]

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,[59] 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.[60]

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 the best to improve bone mass. In addition, if possible, studies that have already performed durability 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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