Physical Activity Interactions with Bone Accrual in Children and Adolescents

Izabella A. Ludwa and Panagiota Klentrou
Brock University,
Canada

1. Introduction

1.1 Osteoporosis and peak bone mass

Osteoporosis is a skeletal disease characterized by low bone mass and the deterioration of the micro architecture of bone tissue resulting in bone fragility and susceptibility to fractures (Gordon, 2003). According to the World Health Organization, osteoporosis is estimated to affect approximately 200 million women worldwide (Kanis, 2007) with the burden of osteoporosis being felt both personally and economically. Although the prevalence of fractures is higher is women, the mortality rate related to fragility fractures is higher in men (Center et al. 1999; Hasserius et al., 2003). Moreover, the annual cost of treating fractures in the United States is projected to increase to $25 billion in 2025 from $17 billion in 2005 (Burge et al., 2005).

Achieving peak bone mass (PBM) during adolescence and the subsequent rate of bone loss are major determinants of bone mass later in life (Hansen et al., 1991). The amount of bone mass achieved early in life has been shown to predict the level of bone mass and the incidence of fracture later in life suggesting that a primary risk factor for the development of osteoporosis is the inability to attain high PBM (Hansen et al., 1991; Heaney et al., 2000). PBM is generally defined as the highest level of bone mass achieved as a result of normal growth and seems to be established, for most sites of the skeleton, by late adolescence (Matkovic et al., 1994). Previous studies (Bonjour et al., 1991; Bailey et al., 1996) have demonstrated the period between 9-20 years of age to be critical in building peak bone mass as 90% of total body bone mineral content (BMC) is accrued by the age of 16 (Elgan et al., 2003; Stager et al., 2006), with the remaining 5-10% of total body bone mass achieved in the third decade (Cadogan et al, 1998). In fact, the most rapid bone mineral accumulation occurs approximately 1 year after the age of peak linear growth (Bailey et al., 1996); around the time of menarche for females (Cadogan et al., 1998). With considerable increases in bone mass occurring during puberty, maximizing PBM during this time is often advocated as the best way to delay age-related bone loss and prevent osteoporotic fractures (Fulkerson et al., 2004; Molgaard et al., 1999; Valimaki et al., 1994).

It appears, therefore, as though there is a critical period, a 'window of opportunity' (MacKelvie et al., 2002), in which we can influence the amount of bone mass we attain. However, bone development is the product of complex interactions between genetic and environmental factors including diet, hormonal influences, and mechanical stimuli (Gordon, 2003; Steelman & Zeitler, 2001). Permanent deficits in PBM are the result of any process that interferes with normal bone mineral accretion during adolescence, such as inadequate calcium intake, physical inactivity, and poor lifestyle choices (related to smoking, alcohol consumption, carbonated beverages) (Javaid & Cooper, 2002). As a result, research in bone growth and development in youth has endeavoured to ascertain the factors important to increasing bone mineral accretion.

1.2 Physical activity

The use of physical activity (PA) in maintaining bone health throughout the lifespan and ultimately preventing osteoporosis has been the focus of considerable research in improving PBM in order to minimize later bone loss (Beck & Snow, 2003). It is generally accepted that engaging in PA during growth enhances bone development (Boot et al., 1997; Janz et al., 2001; Janz et al., 2006). Habitual PA has been shown to enhance lean mass (Baxter-Jones et al., 2008) and bone accrual (Baxter-Jones et al., 2003) in youth, both of which are believed to promote bone health and muscle function in older age (Lefevre et al., 1990). Furthermore, 'when' activity occurs during the lifespan is important as PA at a young age can account up to 17% of the variance in bone mineral density (BMD) seen in individuals in their late 20s (Davies et al., 2005).

In addition to the timing of PA, the method by which PA imparts its benefits on bone is also important. Mechanical loading of sufficient intensity to promote increases in skeletal mass during growth require maximal strains to be greater than those of normal everyday living. If the bone is properly overloaded the load will elicit a modeling response making the bone susceptible to new levels of mechanical demand (Bailey et al., 1996). Some of the largest loads placed on the skeleton are physiological ones resulting from muscle contractions (Rauch et al., 2004; Scheonau & Frost, 2002). Furthermore, gravitational or ground reaction forces are also capable of generating the loads necessary to elicit a favourable response in bone. These two loading methods have lead to investigations of bone responses to different forms of PA with comparisons between athletes and non-athletes. Studies have demonstrated athletes involved in high-impact weight-bearing activities such as gymnastics and running have higher BMD (Lehtonen-Veromaa et al., 2000b, 2000c) than athletes participating in low-impact sports such as swimming; with such athletes exhibiting lower or normal bone densities than non-active youth (Bellew & Gehrig, 2006; Cassell et al., 1996; Courteix et al., 1998). Resistance training and simple jumping exercises have also been shown to have positive effects on femoral BMD in adolescent females and as such can be useful in promoting bone growth and maintaining acquired gains (Fuchs & Snow, 2002; Kato et al., 2006; Nichols et al., 2001). Therefore, different forms of PA, such as resistance training (Nichols et al., 2001) and weight-bearing exercise (Fuchs & Snow, 2002; Lehtonen-Veromaa et al., 2000c) have been shown to have positive effects on the developing skeleton through ground reaction forces and muscle contraction.

Various studies have examined the relationship between PA and markers of bone metabolism (Creighton et al., 2001; Lehtonen-Veromaa et al., 2000a), with little research conducted on markers of bone formation and resorption in relation to different types of sports, particularly in children and adolescents. In female athletes between the ages of 18-26, Creighton et al. (2001) found bone formation to be lower and resorption similar in swimmers compared to basketball, volleyball, and soccer players. In a younger population of boys and girls, ages 9-16 years, no differences were found in any markers of bone metabolism between gymnasts (Lehtonen-Veromaa et al., 2000a), swimmers (Derman et al.,

2008) and controls. Therefore, research investigating the relationship regarding bone markers and different PA types is limited and ambiguous, but even more so in children and adolescents, making it difficult to ascertain the effect of sport on bone. The examination of biochemical measurements of bone turnover, in addition to static measures of bone, is advantageous in the study of skeletal metabolism and growth as they provide an understanding of the dynamic course of bone remodelling. To date, the use of biochemical marks of bone turnover in PA interventions on bone in youth has been extremely limited.

Difficulties in comparing and assessing the benefits of PA on bone during growth reflect the varying methodologies used between studies. PA interventions aimed at improving bone health in youth have been subject to limited maturational comparisons as the majority of interventions have been conducted in one distinct pubertal group. Furthermore, the types of PA interventions that have been applied have varied greatly between studies. Discrepancies in results are due in part to the varying bone assessment techniques that are used across cross-sectional and intervention studies. Many of the aforementioned studies measured improvements in BMD using dual-energy x-ray absorptiometry (DXA). The use of DXA to interpret and evaluate BMD in the growing years can be difficult as there are considerable changes to the size and shape of bone (Bailey et al., 1996; Gordon, 2003; Schoenau et al., 2004), making comparisons between youth problematic. Furthermore, the measurements provided by DXA fail to account for the architecture, organization of tissues, mechanical properties and other factors known to impart bone strength. In addition, the bone assessment techniques used in majority of these studies have provided a static rather than dynamic picture of bone, which could in fact allow for more comparisons across studies.

Evidence supporting the role of PA on bone health has been accumulated from a wide range of studies investigating different activity methods using athletes, non-athletes and inactive individuals. Although these studies contribute to the literature they do not provide us with causality that PA does impart benefits to bone health. In response, there has been an increase in the number of intervention studies conducted, particularly in the school setting. PA interventions in schools are in many ways ideal places to intervene as they allow for a large population of children and adolescents to be targeted in a somewhat controlled environment, regardless of socioeconomic status, in a location where youth already spend a majority of their day during their most skeletally responsive years (Hughes et al. 2007).

2. Methods

Therefore, the primary objective of this chapter is to conduct a systematic review on the effectiveness of exercise and PA interventions to improve bone accrual in children and adolescents. Key finding from controlled intervention trials using various techniques to assess bone mineral density, content and strength changes will be discussed and be grouped according to maturity status. This will hopefully help to shed light on the best time during growth and development to influence bone health and to ascertain if there is indeed a window of opportunity for bone response.

We will also discuss and compare the different types of interventions used to affect changes in bone properties in youth, to determine if there is a modality that is best suited to improving bone development and to what degree these interventions influence changes in bone. Furthermore, we will address the characteristics of loading that have been shown to be best associated with particular structural improvements as interventions can be designed to impart mechanical loading on bone by jumping or by resistance training where the weight-bearing load on bone is applied through muscle. As majority of interventions measure only static properties of bone, this chapter will also be used to discuss bone remodelling parameters influenced by such exercise interventions. To our knowledge there has not been any studies examining the effects of PA interventions on bone remodelling.

2.1 Eligibility criteria and search strategy

The aim of the literature search was to find all available randomized control trials and controlled studies that examined the effects of any type of exercise or PA intervention trial on bone status in healthy (non-clinical, non-athletes) children and adolescents between 6 and 17 years of age. For this review we included all types of bone parameters from various bone assessment techniques (DXA, pQCT, QUS etc.) to be used as primary outcome measures as long as there were at least two measurement time points. Primary outcome measures included areal bone mineral density (aBMD), volumetric bone mineral density (vBMD), bone mineral content (BMC), bone area (BA), cortical thickness, bone strength index (BSI), stress-strain index (SSI), maximal moment of inertia (I^{mas}), section modulus (SM), speed of sound (SOS), broadband ultrasound attenuation (BUA), and markers of bone metabolism.

A computerised search of the MEDLINE and PubMed databases was performed on articles up till 2011 using a comprehensive combination of keywords to describe exercise, bone and participant parameters. The keywords used to describe exercise included: intervention and intervention studies, training, exercise, resistance training, physical education and physical education training, physical activity and motor activity. Bone parameter keywords included: bone mineral, bone density, bone and bones, bone strength, bone accrual and development, bone turnover, resorption, modelling and metabolism. For the participants, keywords such as children, adolescents, boys and girls were used. A total of 2728 were found, their titles and abstracts reviewed to determine if they met the inclusion criteria. Papers from all journals were considered and retrieved electronically or by interlibrary loan.

After screening the articles a total of 35 studies met the criteria and were used for the current review. Studies were grouped according to the maturity status of their participants based on Tanner Staging of development (Tanner, 1962). Participants were grouped as either prepubertal (Tanner 1), early pubertal (Tanner 2 and 3), and pubertal (Tanner 4 and 5) to maintain consistency with other literature review groupings. Studies in which authors provided results for more than one maturity group were divided into two parts (A and B).

3. Results

Table 1 represents the numerical breakdown of all the intervention studies reviewed into particular categories based on the type of intervention that was used, the method in which bone parameters were assessed, the maturity and sex of the population measured. Studies were included more than once if more than one measurement technique was used and if results were separated by sex or maturity group. Table 2 is a detailed summary of the design and outcomes of all the PA intervention studies reviewed, and are grouped according to the participants' maturity status. The results presented in Table 2 express the percentage difference in gain between the experimental groups participating in the intervention in comparison to controls. The results presented in the Table 2 are the final finding after any statistical adjustments have been made.

Type of Intervention		Measurement Technique		Maturational Status		Gender	
School Based		SXA	1	Prepubertal	16	Boys	12
Part of PE Class	23	DPA	1	Early Pubertal	16	Girls	24
At the School	5	DXA	33	Pubertal	7	Boys + Girls	7
Outside School	7	HSA	4	Multi Pubertal^{separate}	4		
Jumping	18	pQCT	5	Multi Pubertal^{together}	5		
General WBPA	14	QUS	3				
Resistance Training	3	Bone Markers	1				

Table 1. Numerical Breakdown by Category of Exercise Interventions for Bone in Youth

Prepubertal corresponds to Tanner Stage 1, early pubertal Tanner Stages 2-3, and pubertal Tanner Stages 4-5. Multi pubertal *separate* are studies with results separated by maturity, with *together* being studies that averaged data for more than one maturity group. Boys + girls reflect studies that did not separate results by sex. PE: physical education; WBPA: weight-bearing physical activity; SXA: single energy x-ray absorptiometry; DXA: dual energy x-ray absorptiometry; DPA: dual photon absorptiometry; pQCT; peripheral QCT; HSA: hip structural analysis; QUS: quantitative ultrasound.

Majority of the intervention studies were school based with 23 of the studies being conducted as part of a regular physical education class and 5 at some point within the school day. Approximately half (51%) of the studies utilized specific jumping interventions that relied on ground reaction forces in order to elicit a positive response on bone. Fourteen studies consisted of general weight bearing types of activities such as running, volleyball, aerobics etc., with only 3 studies specifically using resistance training with free or machine assisted weights. Significant increases in primary bone outcomes were found in 16 jumping interventions, 14 WBPA interventions, and 1 resistance training study. This translated into 79.5% of physical activity interventions positively influencing some form of bone strength parameter in children and adolescents. Furthermore, 5 studies also included calcium interventions which demonstrated benefits to bone in addition to physical activity.

Of the 35 studies reviewed 24 presented results separately for girls, 12 for boys, with 7 studies presenting data for boys and girls together. Moreover, 16 studies conducted interventions in prepubertal and early pubertal children. The smallest number of studies was performed in pubertal youth with a total of 7. All the pubertal interventions were completed on a population of girls, with 1 study (Weeks et al., 2008) including boys in their sample. Based on pubertal groups, an even number of boys and girls were represented in the results of prepubertal youth with 8 studies separately reporting results for boy and girls and 2 grouping results together. In early pubertal children, a larger number of studies were conducted on and included girls. Ten studies reported results separately for girls, 3 for boys and 5 did not distinguish results between genders.

DXA was the measurement technique predominantly used (94%) to assess bone, followed by pQCT (14%) and then QUS (8.5%). In total, 5 studies used more than one technique to determine changes in bone and these were all done in conjunction with DXA measurements. Four studies using DXA also performed hip structural analysis (HSA), which is a new application for DXA allowing for the estimation of geometric contributions to bone strength in the proximal femur and may potentially provide a better representation of bone strength (Bonnick, 2007). It is surprising that such a large percentage of studies utilized DXA given the known methodological issues with assessing changes in bone during growth. Until recently, we had thought no intervention studies had used biochemical markers of bone metabolism. Our extensive literature search found 1 study (Schneider et al., 2007) that measured serum markers of bone formation and resorption in adolescents. As static measures require longer durations for differences to be found, measuring biochemical markers of bone turnover to assess dynamic properties of bone could be advantageous in detecting changes sooner and allow for better comparisons of results between studies.

3.1 Prepubertal interventions

Positive effects of exercise on bone indices were found in 13 of 16 studies (81%), with overall effects ranging from 0.6% to 9.5% depending on the skeletal location and the type of measure (BMC, BMD, etc) taken for studies 7-36 months in duration. The average percent improvements for BMC included 4.5%, 4%, 2%and 1.5% at the lumbar spine (LS), femoral neck (FN), femur and total body (TB) respectively. BMD gains across studies were between 0.6-3% for the LS, FN and TB. The largest gains in girls was in BMC and area of the forearm (12.5% and 13.2% respectively) using peripheral DXA after 36 months of increased physical education class time (Hasselstrom et al., 2008). The one study that used pQCT in this group (Macdonald et al., 2007) was also the study that exhibited the largest bone gains in boys after 16 months of jump training, finding an increase of approximately 25% in BSI (an index of bone structural strength) of the distal tibia. MacKelvie et al. (2004) also presented large gains using HSA, with boys seeing a 12% increase in FN cross-sectional moment of inertia.

Despite the bone gains being similar between boys and girls, the number of studies that reported significant findings differed (4 vs. 7 out of 8 for girls vs. boys respectively). These discrepancies can largely be explained by the differences in the length and type PA intervention employed. MacKelvie et al. (2001) and (2002) were studies that utilized 7 months of school based physical education classes to employ a jump circuit intervention eliciting ground reaction forces 3-5 times one's body weight and demonstrated favourable gains in bone in boys but not girls. Fuchs et al. (2001) also found 7 months of jump training to be favourable to improvements in LS and FN BMC and BMD in prepubertal boys and girls. In fact the gains demonstrated in Fuchs et al. (2001) were greater than those in the MacKelvie et al. (2001, 2001) studies, most likely due to the larger ground reaction forces generated (8.8 vs. 3.5-5 x body weight). Studies at 12 months (Alwis et al., 2008b; Linden et al., 2007) utilizing a weight bearing physical education intervention follow a similar trend with improvements being seen in boys but not girls. The extra intervention time has not helped to elicit a significant positive bone response in the young girls. It is not till 24 months of the same type of weight bearing PA intervention that positive gains are found in girls (Linden et al., 2006). It would therefore appear that improvements in bone as a result of a PA intervention would more likely occur in prepubertal boys than girls. This is particularly true after 7 months of jumping training (MacKelvie et al., 2001, 2002) and 12 months of weight bearing PA (Alwis et al., 2008b; Linden et al., 2007). Improvements in prepubertal girls were seen in studies lasting 24 months in duration (Linden et al. 2006) and any studies demonstrating bone gains in a mixed gendered population (Fuchs et al., 2001; McKay et al., 2000) could be due to greater changes in the boys than the girls.

Table 2. Randomized and Non-Randomized Controlled Studies on the Effects of Exercise on Bone Indices in Youth

Reference	Population	Intervention	Measures	Results
Pre Pubertal (Tanner Stage 1)				
Alwis et al. (2008a)	Boys, White Ex: n=80, Con: n=57 Age range: 6.7-9 yrs All remained TS 1 Randomized by school: 1 Ex + 3 Con.	24 Months Typical PE class: ball games, running jumping, climbing Ex: 40min/day (200min/wk) Con: 60min/wk Compliance: Con 84%, Ex 95%	DXA BMC: total body and L3 vertebra L3 vertebral width HSA of femoral neck	BMC L3: +3% L3 width: +1.3%
Alwis et al. (2008b)	Girls, White Ex: n=53, Con: n=50 Age range: 6.7-9 yrs All remained TS 1 Randomized by school: 1Ex + 3 Con.	12 Months Typical PE class: ball games, running jumping, climbing Ex: 40min/day (200min/wk) Con: 60min/wk Compliance: Con 76%, Ex 95%	DXA and HSA BMC, aBMD, periosteal and endosteal diameter, cortical thickness, CSMI section modulus, and CSA of FN	No significant between group differences were found
Bass et al. (2007)	Boys, White + Asian Total n=88, 7-11 yrs Ex Placebo: n=21 Ex Ca: n=20 No Ex Ca: n=21 No Ex Placebo: n=26 Randomized groups Ca: double blind	8.5 Months Part of PE class: 20min 3x week Hopping jumping, skipping moderate or low impact Ex: Ground rx forces 2-8 x BW No Ex: Ground rx forces 1 x BW Ca: 800mg Ca/day Compliance 86%	DXA BMC: total body, lumbar spine, femur, tibia-fibula, humerus, radius-ulna	Femur BMC: +2% Ex+Ca > all other g Tibia-fibula BMC: +2% ExCa>Ex Place +3% Ex Ca> No Ex(and No Ex Pl NS for BMC in arm
Bradney et al. (1998)	Boys, White N=20 Ex, m=20 Con Age range: 8.4-11.8 All remained TS 1 Randomized by school: 1 Ex + 1 Con	8 Months Program outside of school: aerobics, soccer, volleyball, dance, gymnastics, basketball, weight training 30 minutes, 3 x week	DXA aBMD: total body and lumbar spine, femur, Femoral Midshaft BMC, aBMD and vBMD, and cortical thickness	aBMD TB: +1.2% aBMD LS: +2.8% BMC and aBMD femoral midshaft: + cortical thickness: +
Fuchs et al. (2001)	Boys and Girls, Asian and White Age range: 5.9-9.8 yrs n=45 Ex., n=41 Con Randomized 1 school All remained TS 1	7 Months Activities added to PE classes: 10 min 3x week jumping 50-100 high box jumps, 2 footed Ground rx forces = 8.8 x BW 90% Compliance	DXA BMC and aBMD: lumbar spine and femoral neck BA: femoral neck	BMC LS: +3% BMC FN: +4.5% aBMD LS: +2% aBMD FN: NS BA FN: +2.9%

Table 2. Continued – Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Pre Pubertal (Tanner Stage 1)				
Hassel- strom et al. (2008)	Boys and Girls, White (Ex: n= 135 and 108) (Con: n= 62 and 76) Age Range: 6-8 No Randomization TS 1 and 2	36 Months School based curriculum, time increased: 4 classes 180 min/wk Con: regular school curriculum 90min/wk Activities conducted in classes not mentioned	Peripheral DXA BMC and BMD: Calcaneus and distal forearm	Girls: NS changes in calcaneal and distal forearm BMD BMC forearm: +12.5 forearm area: +13.2% Boys: NS changes in all measures
Linden et al. (2006)	Girls, White Ex: n=49, Con: n=50 Age range: 7-9 All remained TS 1 Randomized by school: 1 Ex + 3 Con.	24 Months Typical PE class: ball games, running jumping, climbing Ex: 40min/day (200min/wk) Con: 60min/wk Ex. Attendance: 90%	DXA BMC and aBMD: TB, LS L2-L4 and L3, FN, and Leg vBMD, bone size: L3 and FN	BMC: L2-L4 +3.8%, L3 +7.2%, Leg +3.0% aBMD: TB +0.6%, L2-L4 +1.2%, L3 +1.6 Leg +1.2% Bone Size: L3 +1.8%, and FN +0.3%
Linden et al. (2007)	Boys, White Ex: n=81, Con: n=57 Age range: 7-9 All remained TS 1 Randomized by school: 1 Ex + 3 Con.	12 Months Typical PE class: ball games, running jumping, climbing Ex: 40min/day (200min/wk) Con: 60min/wk Ex. Attendance: 90%	DXA BMC and aBMD: TB, L3 vertebra, FN Bone Width: L3 and FN	BMC, aBMD, bone width L3: +5.9%, +2. and +2.3%
Macdonald et al. (2007) (Part A)	Boys and Girls Asian and White Ex: n=140, Con: n=72 Age range: 9.6-10.8 Randomized by school: 7 Ex. + 3 Con.	16 Months Ex: 15 min/day PA 5 x week, 5-36 jumps/day 4 x week Con: regular school curriculum Compliance 74%	pQCT BSI distal tibia SSI tibial midshaft	Boys: BSI distal tibia increased ~+2 Girls: NS changes in all measures
MacKelvie et al. (2001) (Part A)	Girls, White + Asian Ex: n=44, Con: n=26 Age range: 9.4-10.6 Randomized by schools: 7 Ex + 7 Con	7 Months Activity added to regular PE class: 10min, 3 x week 50-100 jumps and circuit training, progressing w/jumps Jumping = 3.5-5 x BW Compliance 80% across schools	DXA BMC and aBMD: TB, LS, PF, FN vBMD: FN	NS differences in an of the bone variables measured

Table 2. Continued – Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Pre Pubertal (Tanner Stage 1)				
MacKelvie et al. (2002)	Boys White + Asian Ex: n=61, Con: n=60 Age range: 9.7-10.9 Randomized by schools: 7 Ex + 7 Con	7 Months Activity added to regular PE class: 10min, 3 x week 50-100 jumps and circuit training, progressing w/jumps Jumping = 3.5-5 x BW Compliance 80% across schools	DXA BMC and aBMD: TB, LS, PF, FN vBMD: FN	BMC TB: +1.6% aBMD PF: +1%
MacKelvie et al. (2004)	Boys, White + Asian Ex: n=31, Con: n= 33 Age range: 9.6-10.7 Randomized by schools: 7 Ex + 7 Con	20 Months Activity added to regular PE class: 10min, 3 x week 50-100 jumps and circuit training, progressing w/jumps Jumping = 3.5-5 x BW	DXA and HSA BMC and BA: TB, LB, PF, FN, and TR HAS: PF, NN, TR , FN SM: FN	BMC FN: +4.3% Cross-sectional mom of inertia: +12.35% SM: +7.4%
McKay et al. (2000)	Boys and Girls White and Asian Ex: n=63, C: n=81 Age range: 6.9-10.2 School randomized	8 Months Part of PE classes: jumping, hopping, skipping 2 x week 3 x week 10 tuck jumps Con: regular PE classes	DXA aBMD: TB, LS, PF, FN, and trochanter (TR)	aBMD TR: +1.2%
Petit et al. (2002) (Part a)	Girls, Asian + White Age range: 9.4-10.6 Ex: n=43, Con: n=25 Randomized by schools: 14 schools ethnic stratification	7 Months Part of PE classes: 10-12 min 3x week: 5 x diverse jumping exercise stations Con: regular PE classes Ground rx forces=3.5-5 x BW	DXA and HSA abed: TB, LS, TR, PF cortical thickness, area and SM: PF	NS differences in an of the bone variables measured
Valdimarsson et al. (2006)	Girls, White Ex: n=53, Con: n=50 Age range: 7-9 yrs Ex group come from one school	12 Months Typical PE class: ball games, running jumping, climbing Ex: 40min/day (200min/wk) Con: 60min/wk. 90% Attendance	DXA BMC and aBMD: TB, LS (L2-L4), L3, FN, leg vBMD: L3 and FN	BMC LS: +4.7% BMC L3: +9.5% aBMD LS: 2.8% aBMD L3: 3.1% Bone width L3: +2.9

Table 2. Continued – Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Pre Pubertal (Tanner Stage 1)				
Van Lang-endonck et al. (2003)	Girls Ethnicity not reported Ex: n=21, Con: n=21 21 pairs of monozygotic twins Age range: 8-9yrs	9 Months Ex: 3x week: hopping/jumping Progression: removal of shoes different stimulus Ground rx forces not measured Compliance: Ex 91%	DXA BMC, aBMD, BA: FN and PF	BMC PF: +2.5% aBMD PF: +1.3% BMC FN: +2.0% aBMD FN: +2.4%
Early Pubertal (Tanner Stage 2-3)				
Barbeau et al. (2007)	Girls, Black n=77 Ex., n=83 Con. Age range: 8-12 yrs Recruited from 8 elementary schools	10 Months After school intervention 5 days/week, 80 min PA: 25min skills, 35min MVPA, 20min toning + stretching	DXA Total body BMD, BMC	BMC TB: +4.0% BMD TB: +2%
Courteix et al. (2005)	Girls, White (n=85) Age range: 8-13 yrs Ex Ca: n=12 Ex Placebo: n=42 No Ex Ca: n=10 No Ex Placebo: n=21 Randomized, Blinded	12 Months Ex: 7.2h/week No Ex: 1.2h/week Ca: 800 mg/day Compliance 75% Ex: Participated in weight bearing physical activity	DXA aBMD: TB, LS, FN, WT	aBMD TB: +6.3% aBMD LS: +11% aBMD FN: +8.2% aBMD WT: 9.3% (all Ex Ca > No Ex P NS differences betw other groups
Heinonen et al. (2000) (Part A)	Girls, White Ex: n=25, Con:, n=33 Age range: 10-12yrs Selection to groups decided by teachers	9 Months Step aerobic program: 50 min 2 x week: 20 min of jumping exercises: 100-200 jumps from box (two and one footed) Ground rx forces not measured Compliance: Ex 73%, Study 92%	DXA and pQCT BMC: LS, FN, and TR Cortical area: tibial midshaft	BMC LS: +3.3% BMC FN: +4.0%
Iuliano-Burns et al. (2003)	Girls, White + Asian Total n=64 Age range: 8-9 yrs Mod Ex. Ca: n=16 Mod Ex. Pl: n=16 Low Ex. Ca: n=16 Low Ex. Pl: n=16 Randomized groups	8.5 Months Ex: 20 min 3 x week Mod Ex. Impact: skipping, hopping, jumping. Used hand weights in final 8 weeks Low Ex. Impact: stretching Ca: average of 434 mg/day Compliance: Ex 93%, Study 88%	DXA BMC: LS, Femur, Tibia-Fibula	BMC tibia-fibula: +3% Mod ex>Low E +7.1% Mod Ex Ca > Low Ex. No Pl.

Table 2. Continued - Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Early Pubertal (Tanner Stage 2-3)				
MacKelvie et al. (2001) (Part B)	Girls, White + Asian Ex: n=43, Con: n=64 Age range: 9.9-11.1 yr Randomized by schools: 7 Ex + 7 Con	7 Months Part of PE class: 10min 3x week 50-100 jumps and circuit training, progressing w/jumps Jumping = 3.5-5 x BW Compliance 80% across schools	DXA BMC and aBMD: TB, LS, PF, FN Volumetric BMD: FN	BMC LS +1.8% aBMD LS +1.7% BMC FN: NS aBMD FN: +1.6% vBMD FN: +3.1%
MacKelvie et al. (2003)	Girls, Asian + White Ex: n=33, C: n=43 Age range: 9.3-10.7 Randomized by schools: 7 Ex + 7 Con	20 Months Part of PE class: 10min 3x week 50-100 jumps and circuit training, progressing w/jumps Jumping = 3.5-5 x BW Compliance 42% over 20 Mos.	DX BMC: LS and FN	BMC LS: +3.7% BMC FN: +4.6%
Macdonald et al. (2007) (Part B)	Boys and Girls Asian and White Ex: n=135, Con: n=57 Age range: 9.6-10.8 yrs Randomized by school: 7 Ex. + 3 Con.	16 Months Ex: 15 min/day PA 5 x week, 5-36 jumps/day 4 x week Con: regular school curriculum Compliance 74%	pQCT BSI distal tibia SSI tibial midshaft	NS changes in any of the measures
Macdonald et al. (2008)	Boys and Girls Asian and White Ex: n=140, Con: n=72 Age range: 9-11 yrs Randomized by school: 7 Ex. + 3 Con. TS 1-3	16 Months Ex: 15 min/day PA 5 x week, 5-36 jumps/day 4 x week Con: regular school curriculum Compliance 74%	DXA and HSA FN bone strength, geometry, and BMC BMC: TB, PF, LS	Boys: BMC LS: +2.7 BMC TB: +1.7% Girls: section modu of FN: +5.4% (only in girls with 80% compliance)
Macdonald et al. (2009)	Boys, Asian + White Ex: m=139, Con: n=63 Age range: 9-11 yrs Randomized by school: 7 Ex. + 3 Con.	16 Months Ex: 15 min/day PA 5 x week, 5-36 jumps/day 4 x week Con: regular school curriculum Compliance 74%	pQCT Second moments of area, cortical area, cortical thickness of tibia	Max second mome of area: +3% Trends for increase in cortical area and thickness, but NS

Table 2. Continued - Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Early Pubertal (Tanner Stage 2-3)				
McKay et al. (2005)	Girls and Boys Asian and White Ex: n=51, Con: n=73 Age Range: 9.5-10.5 No Randomization	8 Months Program: Bounce at the Bell 10 counter movement jumps 3 min 3 x day each school day Ground Rx forces: 5 x BW Compliance: Ex 60%, study 100%	DXA and HSA BMC: PF and TR BA: PF and TR Cortical thickness and area: PF	BMC PF: +2.0% BMC TR: +2.7% BA PF: +1.3% BA TR: +2.0% Con > Ex: BMC and BA TB
Meyer et al. (2011)	Boys and Girls, White Ex: n=297, Con: n=205 Age range: 6.6-11.7 yrs Randomized by classes: Ex: 16 classes/ 9 schools, Con: 12 classes/6 schools TS 1-3	12 Mos School based program Ex: regular PE class + 2 extra PE classes that include 10 min jumping activities. 2-5min jumping/balancing tasks through out day Con: regular PE classes	DXA BMC and aBMD: TB, FN, L2-L4	BMC TB: +5.5% BMC FN: +5.4% BMC LS: +4.7% aBMD TB: +8.4% aBMD LS:+7.3% Pubertal stage*grou interaction favored prepubertal childre
Morris et al. (1997)	Girls, Ethnicity not given, but schools stratified according to ethnicity Ex: n=38, Con: n=33 Age range: 8.6-10.4 yrs No randomization Grouped by teachers	10 Months Activity added to regular PE class: 30 min 3 x week Aerobics, skipping, dance, ball games, progressing to weight training Ground rx forces not measured Compliance: Ex 92%, Study 97%	DXA and BMAD BMC: TB, LS, FN, PF aBMD: TB, LS, PF BMAD: LS, FN	BMC TB and LS: +5 BMC FN: +4.5% BMC PF: +8.3% aBMD TB: +2.3% aBMD LS: +3.6% aBMD FN: +10.3% aBMD pF: +3.2% BMAD LS: +2.9%
Nemet et al. (2006)	Boys and Girls, Ethnicity not given Ex: n=12, Con: n=12 Age range: 6-16 yrs Obese participants Randomized groups	3 Months Structured activities to mimic PE classes. Mainly endurance: 50% sports, 50% running and games: 1 hour 2 x week Received nutrition counseling	QUS SOS of left tibia	SOS: +2.9% Difference due to significant SOS decrease (-2.6%) in Con, and NS increa in Ex. (+0.6%)

Table 2. Continued - Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Early Pubertal (Tanner Stage 2-3)				
Nichols et al. (2008)	Boys and Girls, White Total n=112 Age range: 9-10yrs Ex only: n=61 Nutrition only: n=9 Ex + nutrition: n=14 Con: n=28 4 schools randomized 85% TS1 at baseline	20 Months Activity added to PE classes: 8-12min 2 x week: of jumping and skipping Ground Rx forces 2-3 x BW Nutrition: 45min biweely clasees to improve Ca intake Compliance: 80% at 8 months, 73% at 20 months	DXA BMD: TB, LS (L2-L4), PF, and FN BMC: TB, LS, FN, PF Measures taken twice: 8 and 20 months	NS differences between groups fo[r] any of the bone measurements take[n] at 8 and 20 months
Petit et al. (2002) (Part B)	Girls, Asian + White Age range: 9.9-11.1yrs Ex: n=43, Con: n=63 Randomized by schools: 14 schools stratified by ethnic composition	7 Months 10-12 min 3x week 5 x diverse jumping exercise stations Activities done in addition to regular PE classes Con: regular PE classes Ground rx forces=3.5-5 x BW	DXA and HSA aBMD: TR and FN SM: FN cortical thickness: FN	aBMD TR: +1.7% aBMD FN: +2.6% SM FN: +4.0% cortical thickness FN: : +3.2%
Sundberg et al. (2001)	Boys and Girls, White Ex Boys: n=40 Ex Girls: n=40 Con Boys: n=82 Con Girls: n=66 Age range: 12-16 yrs 2 Schools (1 Ex, 1 Con) Recruited grade 6,7 (12-13yrs), follow up grade 9 (15-16yrs) TS 2,3 start TS 4,5 end	3-4 Years Additional time in PE classes Ex: 40min 4 x week 3 of 4 classes: weight bearing activities, jumping, running, gymnastics, ball games 1 of 4 classes: swimming Con: regular PE classes of 60 min 2 x week Compliance: Ex 93%, Con 91%	DXA: BMC, aBMD, vBMD, and bone size: TB, LS, FN SXA: BMC and aBMD: distal radius and ulna ultradistal radius QUS: BUA, SOS, and SI: calcaneus (heel)	3/4 Years Boys: BMC FN: +8% / 0% aBMD FN: +9% / + vBMD FN: 9% / +1 BMC LS: +9% / 0% aBMD LS: 0% / +10 SOS Heel: +1% / + SI Heel: +7% / +2% 3-4 Years Girls: aBMD distal/ultra-distal radius: -6-7%
Pubertal (Tanner Stage 4-5)				
Blimkie et al. (1996)	Girls Ethnicity not reported Ex: n=16, Con: n=16 Age range: 15.9-16.3 All postmenarcheal	6.5 Months Machine assisted weight training 3 x week 4 sets of 12 reps each, with progression every 6 weeks	DPA BMC: TB and LS aBMD: TB and LS	NS differences in a[ny] of the bone variable[s] measured

Table 2. Continued - Studies on the Effects of Exercise on Bone in Youth

Reference	Population	Intervention	Measures	Results
Pubertal (Tanner Stage 4-5)				
Heinonen et al. (2000) (Part B)	Girls, White Ex: n=39, Con:, n=29 Age range: 12.8-15yrs Selection to groups decided by teachers	9 Months Step aerobic program: 50 min 2 x week with 20 min of jump exercises: 100-200 jumps from box (two and one footed) Ground rx forces not measured Compliance: Ex 65%, Study 92%	DXA and pQCT BMC: LS and FN Cortical area: tibial midshaft	NS differences in a of the bone variabl measured
Nichols et al. (2001)	Girls Ethnicity not reported Ex: n=5, Con: 11 Age range: 14-17 yrs All postmenarcheal Randomized groups	15 Months Resistance training program weights and machines: 30-45 min, 3 x week of 15 Progression: weight increase Compliance: Ex. 73%, Study 15%	DXA BMC and aBMD: TB, LS, FN, WT, and TR BMAD: LS and FN	aBMD WT: +3.2% aBMD FN: +2.3%
Schneider et al. (2007)	Girls, White, Hispanic, Asian Ex: n=63, Con: n=59 Age range: Randomized two schools: 1 Ex + 1 Con All given 500mg Ca/d	10 Months, 2 school semesters School based program: 60 min 5 x week (~40min activity time) Variety of aerobic (3 x week), strength building (1 x week), educational (1 x week) activities	DXA + bone turnover BMC and BMD: TB, LS, Hip, thoracic spine, FN and TR Bone formation: OC, BSAP, and CICP Bone resorption: PYD	Thoracic BMC: +4. NS differences in BMD measuremen or markers of bone turnover
Stear et al. (2003)	Girls, White Total n=144 Age range: 16-18 yrs Ca Ex: n=37 Ca No Ex: n=28 Placebo Ex: n=38 Placebo No Ex: n=28 All postmenarcheal Randomized, double blinded 2 schools	15.5 Months Lunch + after school program 45min 3 x week of aerobic to music: moderate to vigorous high impact movements Ground rx forces not measured Ca: 1000mg/day Ex attendance: 36% Ca compliance: 70%	DXA BMC and BA: TB, LS, FN TR, hip, nondominant total, ultradistal and distal third radius	Ca Ex > Placebo N BMC TB: +0.8% BMC LS: +1.9% BMC FN: +2.2% BMC Hip: +2.7 BMC TR: +4.8% Ex > No Ex BA LS: +0.7% BMC Hip: +1.4 BMC TR: +2.6%

Reference	Population	Intervention	Measures	Results
Pubertal (Tanner Stage 4-5)				
Weeks et al. (2008)	Boys and Girls Total n=81 Ex Boys: n=22 Con Boys: n=15 Ex Girls: n=21 Ex Girls: n=23 Age range: 13.5-14.5 Randomized 1 school	8 Months Ex: 10 min 2x week jumping activities as warmup in PE class worked up to ~300 jumps at 1-3 Hz, height 0.2-0.4m Con: 10min 2x week of regular PE class warmup Compliance Ex 80% Study dropout rate 18%	DXA and QUS BMC, BMD, and BA: TB, FN, LS, TR BMAD, CSMI, IBS, and cortical wall thickness BUA: nondominant calcaneus	Boys: BMC TB: +4.3% NS increases Ex boys BUA calcaneus: +3.6 FN area: +1.1% Girls: NS differences NS increases Ex girls BMC FN: +9% BMAD LS: +3.7% LS area: +2.9%
Witzke & Snow. (2002)	Girls, White Ex: n=25, Con:, n=28 Age range: 14-15 yrs All postmenarcheal No randomization	9 Months Ex: 30-45 min 3 x week of resistance and plyometrics training with increasing intensity over 9 months Ground rx forces not measured	DXA BMC: TB, LS, FN, TR	NS differences in BM between groups However, increases in BMC for TB, LS, F TR ranged +0.1-2.1% in Ex group

Table 2. Randomized and Non-Randomized Controlled Studies on the Effects of Exercise **o**n Bone In
Ex: exercise group; Con: control group; BMC: bone mineral content; aBMD: areal bone mineral dens
BMD; BA: bone area; BMAD: bone mineral apparent density (BMD adjusted for BA); TB: total body;
femoral neck; NN: narrow neck; PF: proximal femur;, WT: wards triangle; TR: trochanter; SXA: sing
absorptiometry; DXA: dual energy x-ray absorptiometry; DPA: dual photon absorptiometry; QCT: q
tomography, pQCT; peripheral QCT; HSA: hip structural analysis; QUS: quantitative ultrasound; SC
section modulus; CSMI: cross-sectional moment of inertia; IBS/BSI: index of bone structural strengt
index; BUA: broadband ultrasound attenuations; OC: osteocalcin; BSAP: bone-specific alkaline phos
procollagen peptide; PYD: deoxypyridinoline; Ca: calcium; Rx: reaction; BW: body weight; PE: phys
stage; Pl: Placebo; Grps: Groups; NS: no significant.

3.2 Early pubertal interventions

Eighty-three percent of the PA interventions were capable of creating a positive effect on bone strength parameters in pubertal boys and girls. Study durations ranged from 3 months to 4 years, with both the average and median duration being 12 months. The percent gains in bone ranged anywhere between 1.3-15%; again depending on the measurement location and the technique employed. Of the 16 studies conducted in this group 12 utilized DXA, 3 pQCT, 2 QUS, and 1 SXA. Three of the DXA studies also conducted HSA with 2 of the overall studies employing more than one technique to assess experimental effects on bone. The largest improvements in bone for girls was a 10.3% change in aBMD at the FN following 10 months of a mixed program using jumping, weight bearing exercise and weight training (Morris et al, 1997). This large improvement, however, could be the result of a potential selection bias. In boys, the greatest improvements were in the double digits at 10%, 11%, 14% and 15% for LS aBMD, calcaneal SOS, FN aBMD and vBMD, respectively (Sundberg et al., 2001). These finding in boys were demonstrated after 4 years of increased physical education classes that involved a mixed program of weight bearing and jumping activities. In addition to a PA intervention, 2 of the studies also employed a calcium intervention (Courteix et al., 2005; Iuliano-Burns et al., 2003). These studies (Courteix et al., 2005; Iuliano-Burns et al., 2003) demonstrated calcium supplementation in addition to PA can elicit greater responses in bone than with exercise alone, highlighting the importance of monitoring calcium intake during intervention studies particularly during puberty.

The number of interventions conducted in boys and girls was not equal as it was in the prepubertal group making the discussion on gender differences and effects of PA on bone in this group problematic. Three studies in early pubertal children by the same author (Macdonald et al., 2007, 2008, 2009) incorporated 16 months of 60 minute weekly classroom PA including a bone building program of 5-36 jumps per day 4 times a week. Using pQCT, DXA and HSA these studies demonstrated no significant changes in bone strength in the tibia, but improvements in tibial geometry and bending resistance in boys (Macdonald et al., 2007, 2009). Boys also experienced improvements in lumbar spine BMC and whole body BMC, with girls seeing increases in section modulus (a measure of bending resistance) of the femoral neck (Macdonald et al., 2008). These results imply there may be gender differences in the properties of bone that improve following an exercise intervention. There are 3 reasons why the trends shown by Macdonald et al. (2007, 2009) failed to reach significance. Firstly, there was an uneven distribution of sample size, maturity status and gender between groups making some of the groups underpowered. Secondly, as ground reaction forces were not reported it is possible that external loads applied during the intervention was not high enough to instigate a loading response in bone. Third and most likely, the benefits of the jumping intervention could have been attenuated due to the low compliance to the program. In fact, Macdonald et al. (2008) reported significant findings for individuals with 80% compliance. This notion is supported by 3 studies that (MacKelvie et al., 2001, 2003; Petit et al., 2002) demonstrated improvements in BMC, aBMD and vBMD in girls following a shorter jumping program (7 months) eliciting larger ground reaction forces (3.5-5 x body weight) and for whom study compliance was 80% (MacKelvie et al., 2001).

Not only does it appear that larger loading responses are needed to elicit positive changes in bone, but also the way in which that load is applied to bone matters. A large number of studies (69%) employed specific jumping exercises as part of their intervention demonstrating that short, irregular, diverse large loads at varying times of the day are sufficient to instigate bone responses (Heinonen et al., 2000; MacKelvie et al., 2001; McKay et al. 2005, Meyer et al., 2011; Petit et al., 2002). Unlike the studies conducted in prepubertal youth, interventions prescribing weight bearing activities do not need to be conducted over long periods of time to see similar responses in bone. Barbeau et al. (2007), Courteix et al. (2005), and Morris et al. (1997) demonstrated such improvements in 7-12 months time. Interventions in which there were no improvements in bone parameters attributed this to higher levels of leisure PA in the non-experimental groups, increased bone mass at baseline, and earlier menarcheal status (Petit et al., 2002; Sundberg et al., 2001). All of these factors would contribute to bone indices being elevated prior to the intervention allowing for only small changes to occur and in turn masking any effects of the intervention program.

3.3 Pubertal interventions

The fewest PA interventions were conducted in pubertal youth, with all 7 involving girls and 1 including boys. The types of interventions included resistance training (Blimkie et al., 1996; Nichols et al., 2001; Witzke & Snow, 2002), jumping trials (Weeks et al., 2008), and those with a variety of different weight-bearing activities (Heinonen et al., 2000, Schneider et al., 2007, Stear et al., 2003). DXA was the predominant method used to asses bone in this population, with one study using DPA (Blimkie et al., 1996). Three of the studies that used DXA also used an alternate method such as pQCT (Heinonen et al. 2000), QUS (Weeks et al., 2008) and serum biochemical markers of bone turnover (Schneider et al., 2007). Half of the trials demonstrated significant changes (0.7-4.9%) in bone following their interventions, with 3 of the studies demonstrating non-significant trends (Schneider et al., 2007; Weeks et al., 2008, Witzke & Snow, 2002). Of those studies that reported significant trends, one included both an exercise and calcium intervention and observed bone mineral advantages at the femoral neck, lumbar spine and total body in adolescent girls receiving both interventions (Stear et al., 2003). Albeit the combination of calcium and exercise generated greater improvements, those girls receiving just the exercise also demonstrated significant changes at the hip. Schneider et al. (2007) provided all pubertal girls with 500mg of calcium per day and unlike Stear et al. (2003) only observed significant changes in thoracic BMC despite improved trends in BMD and markers of bone turnover. It is possible that these results failed to reach significance as the intervention by Schneider et al. (2007) was shorter in duration than Stear et al. (2003), 10 vs. 15.5 months respectively. Moreover, as everyone in Schneider et al.'s (2007) study was taking calcium the room for improvements may have been smaller than Stear et al.'s (2003) who observed the greatest differences between exercising calcium takers and non- exercising non-calcium consuming controls. Regardless of these discrepancies, the one thing that is clear from these two studies and those described in the early pubertal section (Courteix et al., 2005; Iuliano-Burns et al., 2003), is that calcium is important to bone health and its use during PA interventions will greatly affect results.

Three investigations of the effects of resistance training on bone mineral accrual in pubertal girls were completed, with only 1 reporting significant changes in bone indices (Nichols et al., 2001). A major difference between the studies that did not find significant changes (Blimkie et al., 1996; Witzke & Snow, 2002) and the one that did (Nichols et al., 2001) was the duration of the intervention trial. It appears that with resistance training a longer trial of approximately 15 months is necessary to demonstrate significant improvements in bone, similarly to the 15.5 months of WBPA in Stear et al. (2003). In addition to resistance training Witzke & Snow (2002) used plyometric training and the utilization of this may have resulted in the strong non-significant trends, demonstrating that perhaps shorter trials that include ground reaction forces can be efficacious at improving bone. Results from studies examining jumping trials (Heinonen et al., 2000; Weeks et al., 2008) 8-9 months in duration have been ambiguous. Heinonen et al. (2000) failed to measure significant changes in bone; however, Weeks et al. (2008) did observe improved total body BMC in pubertal boys but not girls. Interestingly, Weeks et al. (2008) did measure large percent changes, albeit non-significant trends, in many different parameters of bone strength in both boys and girls. These trends could be the result of the greater ground reaction forces used in this study compared to that of Heinonen et al. (2000) and could possibly have reached significant if the length of the trial were longer. A common theme in all of these studies not having significant findings or 'almost' measuring differences is poor compliance. If it were not for the issues with compliance, there is a large probability these studies would have found significant results.

Another important factor as to why very few studies reported changes in pubertal youth is due to how bone is accrued in this maturity group. According to Bailey et al. (1996, 1999) peak velocity of BMC accrual for the whole body occurs approximately 0.7-1 year after peak linear growth around the time of menarche, which corresponds to approximately 12-13 years of age in girls. The pubertal girls in the 7 studies reviewed were between the ages of 13 and 18, putting them after the point of peak BMC velocity accrual where the velocity at which they are accruing bone is actually decreasing. The schematic representation of PBM and the rate at which bone mass is accrued over time resembles a dose response curve. It would appear that the pubertal girls in these studies are nearing their PBM, putting them near the plateau of the accrual process, and therefore both the rate and amount of BMC that can be accrued during this time is less. As a result, detecting significant changes will be difficult. Just because these percent gains are small and non-significant statistically does not mean that they are not meaningful. Turner and Robling (2003) demonstrated that a 5.4% and 6.9% gain in aBMD and BMC respectively, translated into a 64% and 94% increase in the amount of force and energy a bone could absorb before failure. This suggests that even small changes in bone mass, which are marginally detectable by DXA can significantly improve bone strength. Therefore a little bone goes a long way.

4. Discussion

4.1 The window of opportunity for bone adaptations

The early pubertal period may be the best time to generate skeletal adaptations to PA. Studies conducted in more than one maturity group demonstrated positive bone gains in early pubertal girls with no significant increases in prepubertal (MacKelvie et al., 2001; MacKelvie et al., 2003; Petite et al., 2002) or pubertal (Heinonen et al., 2000) girls. When reviewing all of the intervention studies the greatest gains in bone on average, regardless of sex, skeletal location and type of activity used, was during the early pubertal years. These results are more definitive in girls as a larger proportion of intervention studies have been conducted on females across puberty, with the sample of boys decreasing with maturity. Despite this trend, longer duration intervention studies where boys most likely transitioned from pre- to early puberty also demonstrate larger gains in bone than in just prepubertal boys (MacKelvie et al., 2004). Larger skeletal gains were also observed in interventions trials that supplemented with calcium during early puberty (Courteix et al., 2005; Iuliano-Burns et al., 2003) compared to those supplementing in prepubertal (Bass et al., 2007) and pubertal

(Schneider et al., 2007; Stear et al., 2003) stages. Moreover, the velocity for BMC accrual is highest in early puberty prior to menarche (in girls) (Bailey et al., 1996, 1997; Cadogan et al., 1998, after which accrual rates decrease with age plateauing in late adolescence upon achieving PBM (Davies et al., 2005). Therefore, the 'window of opportunity' to impart the largest influences on bone development may be during early puberty.

4.2 Optimal physical activity interventions for bone adaptations

Based on our systematic review of the literature we can deduce that regular exercise can be an effective way to improve bone density, size, and shape; in turn improving the mechanical strength of bone. With the variability in the types of interventions used and how they were employed there is no clear consensus on exactly how we should prescribe exercise in order to see the greatest returns in terms of bone health. However, in reviewing the literature, regardless of pubertal stage, the duration of the trial and the intensity in which it was employed appeared to matter. If interventions were short in duration (8-10 months) those that utilized jumping activities with high ground reaction forces received the most positive results (Bass et al. 2007; Fuchs et al., 2001; MacKelvie et al., 2001, 2002; McKay et al., 2005; Petit et al., 2002; Weeks et al., 2008). If weight bearing PA or resistance training was utilized the length of the intervention needed to be longer (10-24 months depending on maturity), in order to see significant gains in bone (Alwis et al., 2008a; Courteix et al., 2005; Linden et al., 2006, 2007; Morris et al., 1997; Nichols et al., 2001; Stear et al., 2003; Valdimarsson et al., 2006). In terms of frequency of exercise, Turner & Robling (2003) suggest it is better to shorten each individual exercise session than to reduce the number of sessions, as jump training has been shown to improve BMC when performed at least 3 time per week but not when reduced to 2 time per week, with gains increasing up to 5 days a week with 2 shorter session in one day. This is reflected in the interventions reviewed with significant gains in bone indices being observed in trials occurring 3-5 times per week. The most recent intervention study reviewed (Meyer et al., 2011) is a good example of these last two concepts by demonstrating that a variety of different activities in one intervention at random times of the day can be effective in eliciting bone gains. Therefore, PA is beneficial for bone health and irregular activities utilizing jump and resisting training to weight bearing activities are some of the best ways to elicit an adaptive response in bone. Not only is the variety beneficial for bone but it can also help to alleviate the boredom that accompanies exercise regimens. Remember that in terms of bone change really is good!

4.3 Methodological issues

DXA was the technique most often used in the PA intervention trials reviewed, and was used to measure BMC and BMD in various skeletal regions of the body. However, BMD assessed using DXA is an estimation of 'true' bone density and the areal density that is expressed is affected by bone size making it difficult to interpret, evaluate and compare BMD in the growing years when there are considerable changes to the size and shape of bone in children (Bailey et al., 1996; Fulkerson et al., 2004; Gordon, 2003; Schoenau et al., 2004). Moreover aBMD is a surrogate measure for bone strength and even though BMC and BMD are related to bone strength inferring information regarding strength from studies using these measures can be misleading. This fact is represented in the many studies citing increases in BMD and BMC that were not always significant. It is possible that DXA may not be sensitive enough to detect small changes in bone particularly at a time in development when small changes are difficult to come by, like later in puberty when the rate of BMC accrual is decreasing. However, even these small detectable changes in bone mass using DXA can signify improvements in bone strength most likely by favourably altering bone geometry (Turner & Robling, 2003). Therefore the best parameter for assessing the effectiveness of PA interventions on bone would be to use a technique that includes measures of bone strength but also bone shape and size.

pQCT is a method that can be used to detect true vBMD, bone strength, shape and size. Unfortunately, only 5 of the studies that we reviewed utilized this method. An advantage of using pQCT to compare bone structural differences is that it has the capability to demonstrate bone strength adaptations in bone size via changes in cortical thickness or area through investigation of periosteal or endocortical expansion (Haapasalo et al., 2000; Kontulainen et al., 2002; Nikander et al., 2009). Moreover, these measurements indirectly provide an idea of the dynamic course of bone and how bone is metabolized to infer strength. However, to date only 1 study has directly measured biochemical markers of bone turnover in response to a PA intervention (Schneider et al., 2007). Measuring bone turnover would allow for detection of potential exercise effects sooner, as gains in bone markers have been demonstrated after 8 weeks of resistance training in women 20 years of age (Lester et al., 2009). Moreover, reference values for many of the markers have been set within the literature allowing for comparison across studies; something that is difficult to do for static measures of bone as the standards and definitions defining low bone mass are available only for postmenopausal women and not youth.

One way of avoiding this issue is to cease relating bone mass and strength to age, and relate it instead to muscle function (Schoenau & Fricke, 2008). This new methodological concept is based on the thought that the critical property of bone is strength rather than weight and that what influences bone strength are the mechanical loads it must endure either through PA or muscle contraction. Regardless of the mode of mechanical load the stability of the bone must be adapted to muscle strength, in a sense creating a functional muscle-bone unit (Schoenau & Fricke, 2008). Such an analysis removes the concept of a 'peak bone mass', which in fact is something we are not capable of measuring for an individual. Instead this approach allows for determination and comparison of bone deficits irrespective of age as bone strength is related to the strength and function of muscle (Schoenau & Fricke, 2008). Moreover, this approach moves away from looking at bone as a separate entity but as functionally linked system.

4.4 Psycho-social factors

It is also important to consider the psycho-social factors that are believed to affect bone health; these include osteoporosis beliefs, knowledge and practises. Women's willingness to adopt healthy behaviors depends on their level of knowledge of osteoporosis (Cook et al., 1991; Jamal et al., 1999). Majority of research examining calcium intake and PA with respect to osteoporosis knowledge and beliefs, and as preventative behaviours have been investigated in post menopausal women (Tudor-Locke & McColl, 2000). A few researchers have examined these criteria in younger women (Kasper et al., 1994, 2001; Wallace, 2002), let alone in adolescents (Anderson et al., 2005; Schrader et al., 2005). A lack of knowledge about osteoporosis risk factors (insufficient calcium intake and daily PA), as well as perceptions of low risk for developing osteoporosis, has been reported among college women (Kasper et al., 2001) and adolescent females (Anderson et al., 2005). Moreover, studies have suggested exercise self-efficacy and barriers to exercise are the best predictors of weight bearing exercise and dietary intake (Wallace, 2002), with educational interventions targeting youth demonstrating improvements in bone health knowledge, increases in intake of calcium rich foods and calcium self-efficacy (Schrader et al., 2005; Sharma et al., 2010). Therefore, knowing which factors will help children and adolescents adopt healthy 'bone' behaviors is important to making the exercise interventions we reviewed a reality.

Based on our literature review we know that structured and controlled PA interventions are effective in eliciting bone gains in youth. In order for youth to get involved in osteoporosis preventative behaviors such as PA they need to be able intervene in their daily lives on their own. McWannell et al. (2008) conducted a study to determine whether a structured high impact exercise program would be more effective in improving BMC and BMD than a lifestyle intervention program promoting PA in middle school children 10-11 years of age. This study demonstrated that the structured high impact PA program significantly improved total body BMC and BMD compared to controls after 9 weeks, with the lifestyle intervention seeing insignificant trends for bone gains. Moreover, a health plan-based lifestyle intervention designed at improving both diet and PA in adolescent girls outside of school demonstrated significant improvements in BMD and bone metabolism due to greater consumption of calcium and vitamin D (DeBar et al., 2006). However, when a larger focus was placed on PA and the adolescent girls taught how to properly conduct exercises a self-led PA program proved to be just as significant in improving bone strength parameters as a structured teacher-led PA program (Murphy et al., 2006). More importantly, those girls involved in the self-led PA program continued to exercise after the intervention had ceased, whereas the teach-led group did not. Therefore, it is not only important to get youth physically active in order to improve bone health, it is just as important to develop the personal skills necessary to direct their own activity.

5. Conclusions

With the current growing inactivity and unhealthy dietary habits, the body composition of youth is changing making this systemic review regarding the different types of exercise interventions, those utilizing resistance training vs. ground reaction forces, relevant. For long-term gains, it appears that short-term high-impact exercises undertaken early in childhood (pre and early puberty) if sustained into adulthood has a persistent effect over and beyond that of normal growth and development. Benefits in total body, lumbar spine, thoracic and femoral neck BMC (2.3-4.4%) as well as BMC at the hip (1.4%) have respectively been observed 3 (Gunter et al., 2008b) and 5 years (Gunter et al., 2008) following the jumping intervention by Fuchs et al. (2001). It is therefore redundant in some respect to conduct more PA interventions, unless more advanced techniques of measuring bone are used, as it is apparent from this review that PA in a structured controlled environment is effective in creating positive gains in bone. The next step is to influence change by schools either adopting these activities into their physical education curriculums or providing youth with the tools to administer this change on their own. Therefore, the examination of behavioral, social-psychological variables in addition to physical determinants of skeletal development provides a holistic multi-faceted conceptual framework of bone health that will provide the tools to better disseminate knowledge on positive bone building activities in hopes of creating life-long PA practices.

6. References

Alwis, G.; Linden, C.; Ahlborg, H.G.; Dencker, M.; Gardsell, P. & Karlsson, M.K. (2008a). A 2-year school-based execise programme in pre-pubertal boys induces skeletal benefits I lumbar spine. *Acta Pediatrica*, Vol. 97, (July 2008), pp. 1564-1561

Alwis, G.; Linden, C.; Stenevi-Lundgren, S.; Ahlborg, H.G.; Besjakov, J.; Gardsell, P. Karlsson, M.K. (2008b). A one-year exercise intervention program in pre-pubertal girls does not influence hip structure. *BMC Musculoskeletal Disorders,* Vol. 9, No. 9,

Anderson, K.D., Chad, K.E. & Spink, K.S. (2005). Osteoporosis knowledge, beliefs, and practices among adolescent females. *Journal of Adolescent Health*, Vol. 36, No. 4, (April 2005), pp. 305-312

Bailey, D.A. (1997). The Saskatchewan Pediatric Bone Mineral Accrual Study: Bone mineral acquisition during the growing years. *Journal of Sports Medicine,* Vol. 18, Suppl. 3, pp. S191-S194

Bailey, D.A.; Faulkner, R.A. & McKay, H.A. (1996). Growth, physical activity, and bone mineral acquisition. *Exercise & Sport Sciences Review,* Vol. 24, No. 1, (January 1996), pp. 233-266

Barbeau, P.; Johnson, M.; Howe, C.; Allison, J.; Davis, C.L.; Gutin, B. & Lemon, C.R. (2007). Ten months of exercise improves general and visceral adiposity, bone, and fitness in black girls. *Obesity*, Vol. 15, No. 8, (August 2007), pp. 2077-2085

Bass, S.L.; Naughton, G.; Saxon, L.; Iuliano-Burns, S.; Daly, R.; Briganti, E.M.; Hume, C. & Nowson, C. (2007). Exercise and calcium combined results in a greater osteogenic effect than either factor alone: a blinded randomized placebo-controlled trial in boys. *Journal of bone and Mineral Research*, Vol. 22, No. 3, (Dec 2006), pp. 458-465

Baxter-Jones, A.D.; Eisenmann, J.C.; Mirwald, R.L.; Faulkner, R.A. & Bailey, D.A. (2008). The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. *Journal of Applied Physiology,* Vol. 105, No. 2, (August 2008), pp. 734-741

Baxter-Jones, A.D.; Mirwald, R.L.; McKay, H.A. & Bailey, D.A. (2003). A longitudinal analysis of sex differences in bone mineral accrual in healthy 8-19-year-old boys and girls. *Annals of Human Biology,* Vol. 30, No. 2, (March 2003), pp. 160-175

Beck, B.R. & Snow, C.M. (2003). Bone health across the lifespan – exercising our options. *Exercise and Sport Sciences Reviews,* Vol. 31, No. 3, (July 2003), pp. 117-122

Bellew, J.W. & Gehrig, L. (2006). A comparison of bone mineral density in adolescent female swimmers, soccer players, and weight lifters. *Paediatric Physical Therapy,* Vol. 18, No. 1, (Spring 2006), pp. 19-22

Blimkie, C.J.; Rice, S.; Webber, C.E.; Martin, J.; Levy, D. & Gordon, C.L. (1996). Effects of resistance training on bone mineral content and density in adolescent females. *Canadian Journal of Physiology and Pharmacology,* Vol. 74, No. 9, (April 1996), pp. 1025-1033.

Bonjour, J.P.; Theintz, G.; Buchs, B.; Slosman, D. & Rizzoli, R. (1991). Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. *Journal of Clinical Endocrinology and Metabolism*, Vol. 73, No. *3*, (September 1991), pp. 555-563

Bonnick, S.L. (2007). Beyond BMD with DXA. *Bone,* Vol. 41, No. 1, (July 2007), pp. S9-S12

Boot, A.M.; De Ridder, M.A.J.; Pols, H.A.P.; Krenning, E.P. & de Muink Keizer-Schrama, S.M.P.F. (1997). Bone mineral density in children and adolescents: relation to puberty, calcium intake, and physical activity. *Journal of Clinical Endocrinology and Metabolism,* Vol. 82, No. 1, (January 1997), pp. 57-62

Bradney, M.; Pearce, G.; Naughton, G.; Sullivan, C.; Bass, S.; Beck, T.; Carlson, J. & Seeman, E. (1998). Moderate exercise during growth inprepubertal boys: changes in bone mass, volumetric density and bone strength: a controlled prospective study. *Journal of Bone and Mineral Research,* Vol. 13, No. 12, (December 1998), pp. 1814-1821

Burge, R.; Dawson-Hughes, B.; Solomon, D.H.; Wong, J.B.; Kind, A. & Tosteson, A. (2007) Incidence and economic burden of osteoporosis-related fractures in the United States, 2005-2025. *Journal of Bone and Mineral Research,* Vol. 22, No. 3, (March 2007), pp. 465-475

Cadogan, J.; Eastell, R.; Jones, N. & Barker, M. (1997). Milk intake and bone mineral acquisition in adolescent girls: randomized, controlled intervention trial. *British Medical Journal,* Vol. 315, No. 7118, (November 1997), pp. 1255-1260

Cadogan, J.; Blumsohn, A.; Barker, M.E. & Easterll, R. (1998). A longitudinal study of bone gain in pubertal girls: anthropometric and biochemical correlates. *Journal of Bone and Mineral Research*, Vol. 13, No. 10, (October 1998), pp. 1602-1612

Cassell, C.; Benedict, M. & Specker, B. (1996). Bone mineral density in elite 7- to 9-yr-old female gymnasts and swimmers. *Medicine and Science in Sports and Exercise*, Vol. 28, No. 10, (October 1996), pp. 1243-1246

Center, J.R.; Nguyen, T.V.; Schneider, D.; Sanbrook, P.M. & Eisman, J.A. (1999) Mortality after all major types of osteoporotic fracture in men and women: an observational study. *Lancet,* Vol. 353, No. 9156, (March 1999), pp. 878-882

Cook, B.; Noteloviz, M.; Rector, C. & Krischer, J.P. (1991). An osteoporosis patient education and screening program: Results and implications. *Patient Education and Counselling*, Vol. 17, Vol. 2, (April 1001), pp. 135-145

Courteix, D. ; Jaffre, C. ; Lespessaille, E. & Benhamou, L. (2005). Cumulative effects of calcium supplementation and physical activity on bone accretion in premenarchal children: a double-blind randomised placebo-controlled trial. *International Journal of Sports Medicine,* Vol. 26, No. 5, (September 2004), pp. 332-338

Courtiex, D.; Lespesailles, E.; Loiseau-Peres, S.; Obert, P.; Germain, P. & Benhamou, C.L. (1998). Effect of physical training on bone mineral density in prepubertal girls: a comparative study between impact-loading and non-impact loading sports. *Osteoporosis International,* Vol. 8, No. 2, (March 1998), pp. 152-158

Creighton, D.L.; Morgan, A.L.; Boardley, D. & Brolinson, G. (2001). Weight-bearing exercise and markers of bone turnover in females and athletes. *Journal of Applied Physiology*, Vol. 90, No. 2, (February 2001), pp. 565-570

Davies, J.H.; Evans, B.S. & Gregory, J.W. (2005). Bone mass acquisition in healthy children. *Archives of Disease in Childhood,* Vol. 90, No. 4, (April 2005), pp. 373-378

DeBar, L.L.; Ritenaugh, C.; Aickin, M.; Orwoll, E.; Elliot, D.; Dickerson, J.; Vuckovic, N.; Stevens, V.J.; Moe Esther, and Irving, L.M. (2006). A health plan-based lifestyle intervention increases bone mineral density in adolescent girls. *Archives of Pediatric and Adolescent Medicine,* Vol. 160, Vol. 12, (December 2006), pp. 1269-1276

Derman, O.; Cinemre, A.; Kanbur, N.; Dogan, M.; Kilic, M. & Karaduman, E. (2008). Effect of swimming on bone metabolism in adolescents. *Turkish Journal of Pediatrics,* Vol. 50, No. 2, (March 2008), pp. 149-154

Elgan, C.; Samsioeb, G. & Dykesa, A. (2003). Influence of smoking and oral contraceptives on bone mineral density and bone remodeling in young women: a 2-year study. *Contraception*, Vol. 67, No. 6, (June 2003), pp. 439–447

Fuchs, R.K.; Bauer, J.J. & Snow, C. (2001). Jumping improves hip and lumbar spine bone mass in prepubescent children: a randomized controlled trial. *Journal of Bone and Mineral Research*, Vol. 16, No. 1, (January 2001), pp. 148-156

Fuchs, R.K. & Snow, C.M. (2002). Gains in hip bone mass from high-impact training are maintained: A randomized controlled trial in children. *Journal of Pediatrics,* Vol. 141, No. 3, (September 2002), pp. 357-362

Fulkerson, J.A.; Himes, J.H.; French, S.A.; Jensen, S.; Petit, M.A.; Stewart, C.; Story, M.; Ensrud, K.; Fillhouer, S. & Jacobson, K. (2004). Bone outcomes and technical measurement issues of bone health among children and adolescents: considerations for nutrition and physical activity intervention trials. *Osteoporosis International*, Vol. 15, No. 12, (December 2004), pp. 929-941

Gordon, C.M. (2003). Normal bone accretion and effects of nutritional disorders in childhood. *Journal of Women's Health*, Vol. 12, No. 2, (February 2003), pp. 137-142

Gunter, K.; Baxter-Jones, A.D.G.; Mirwald, R.; Amstedt, H.; Fuches, R.K.; Durski, S. & Snow, C. (2008). Impact exercise increases BMC during growth: an 8-year longitudinal study. *Journal of Bone and Mineral Research,* Vol. 23, No. 7, (Dec 2007), pp. 986-993

Gunter, K.; Baxter-Jones, A.D.G.; Mirwald, R.; Amstedt, H.; Fuller, A.; Durski, S. & Snow, C. (2008b). Jumping skeletal health: a 4-year longitudinal study assessing the effects of jumping on skeletal development in pre and circum pubertal children. *Bone,* Vol. 42, No. 4, (April 2008), pp. 710-718

Haapasalo, H.; Kontulainen, S.; Sievan, H.; Kannus, P.; Jarvinen, M. & Vuori, I. (2000). Exercise-induced bone gain is due to enlargement in bone size without a change in volumetric bone density: a peripheral quantitative computed tomography study of the upper arms of male tennis players. *Bone,* Vol. 27, Vol. 3 (Sept 2000), pp. 351-357

Hansen, M. A.; Overgaard, K.; Riis, B.J. & Christiansen, C. (1991). Role of peak bone mass and bone loss in postmenopausal osteoporosis: 12 year study. *British Medical Journal*, Vol. 303, No. 6808, (October 1991), pp. 961-964

Hasselstrom, H.A.; Karlsson, M.K.; Hansen, S.E.; Gronfeldt, V.; Froberg, K. & Anderson, L.B. (2008). A 3-year physical activity intervention program increases the gain in bone mineral and bone width in prepubertal girls but not boys: the prospective Copenhagen School Child Interventions Study (CoSCIS). *Calcified Tissue International,* Vol. 83, No. 4, (October 2008), pp. 243-250

Hasserius, R.; Karlsson, M.K.; Nilsson, B.E.; Redlund-Johnell, I. & Johnell, O. (2003) Prevalent vertebral deformities predict increased mortality and increased fracture rate in both men and women: a 10-year population-based study of 598 individuals from the Swedish cohort in the European Vertebral Osteoporosis Study. *Osteoporosis International,* Vol. 14, No. 1, (January 2003), pp. 61-68

Heaney, R.; Abrams, S.; Dawson-Hughes, B.; Looker, A.; Marcus, R. Matkovic, V. & Weaver, C. (2000). Peak bone mass. *Osteoporosis International* , Vol. 11, No. 12, pp. 985-1009

Heinonen, A.; Sievanen, H.; Kannus, P.; Oja, P.; Pasanen, M. & Vuori, I. (2000). High-impact exercise and bone of growing girls: a 9-month controlled trial. *Osteoporosis International*, Vol. 11, No. 12, (June 2000), pp. 1010-1017

Hughes, J.M.; Novotny, S.A.; Wetzsteon, R.J. & Petit, M.A. (2007). Lessons learned from school-based skeletal loading intervention trials: putting research into practice. *Medicine and Sport Science,* Vol. 51, pp. 137-158

Iuliano-Burns, S.; Saxon, L.; Naughton, G.; Gibbons, K. & Bass, S.L. (2003). Regional specificity of exercise and calcium during skeletal growth in girls: a randomized controlled trial. *Journal of Bone and Mineral Research,* Vol. 18, No. 1, (January 2003), pp. 156-162

Jamal, S.A., Ridout, R.; Chase, C.; , Fielding, L.; Rubin, L.A. & Hawker, G.A. (1999). Bone mineral density testing and osteoporosis education improve lifestyle behaviors in premenopausal women: a prospective study. *Journal of Bone Mineral Research*, Vol. 14, No. 12, (December 1999), pp. 2143-2149,

Janz, K.F.; Burns, T.L.; Torner, J.C.; Levy, S.M.; Paulos, R.; Willing, M.C. & Warren, J.J. (2001). Physical activity and bone measures in young children: the Iowa bone development study. *Pediatrics,* Vol. 107, No. 6, (June 2001), pp. 1387-1393

Janz, K.F.; Gilmore, J.; Burns, T.; Levy, S.; Torner, J.; Willing, M. & Marshall, T. (2006). Physical activity augments bone mineral accrual in young children: the Iowa bone development study. *Journal of Pediatrics,* Vol. 148, No. 6, (June 2006), pp. 793-799

Janz, N.K.; Champion, V.L. & Stretcher, V.J. (2002). The health belief model. In: *Health Behaviour and Health Education: Theory, Research and Practice,* Glanz, K., Rimer, B. K., & Lewis, F. M. (Eds), pp. 45-63, John Wiley and Sons Inc., San Francisco, Ca.

Javiad, M.K. & Cooper, C. (2002). Prenatal and childhood influences on osteoporosis. *Best Practice & Research Clinical Endocrinology & Metabolism,* Vol. 16, No. 2, (June 2002), pp. 349-367

Kanis, J.A.; on behalf of the World Health Organization Scientific Groups. (2007). Assessment of osteoporosis at the primary health-care level. Technical Report. World Health Organization Collaborating Centre for Metabolic Bone Diseases, University of Sheffield, UK

Kasper, M.; Peterson, M. & Allegrante, J. (2001). The need for comprehensive educational osteoporosis prevention programs for young women: results from a second osteoporosis prevention survey. *Arthritis and Rheumatism*, Vol. 45, No. 1, pp. 28-34

Kasper, M.; Peterson, M.; Allegrante, J.; Galsworthy, T. & Gutin, B. (1994). Knowledge, beliefs, and behaviors among college women concerning the prevention of osteoporosis. *Archives of Family Medicine*, Vol. 3, No. 8, (August 1994), pp. 696-702

Kato, T.; Terashima, T.; Yamashita, T.T.; Hatanaka, Y.; Honda, A. & Umemura, Y. (2006). Effect of low-repetition jump training on bone mineral density in young women. *Journal of Applied Physiology,* Vol. 100, No. 3, (March 2006), pp. 839-843

Kontulainen, S.; Sievanen, H.; Kannus, P.; Pasanen, M. & Vuori, I. (2002). Effect of long-term impact-loading on mass, size and estimated strength of humerus and radius of female racquet-sports players: a peripheral quantitative tomography study between young and old starters and controls. *Journal of Bone and Mineral Research,* Vol. 17, No. 12, (December 2002), pp. 2281-2289

Lefevre, J.; Beunen, G.; Steens, G.; Claessens, A. & Renson, R. (1990). Motor performance during adolescence and age thirty as related to age at peak height velocity. *Annals of Human Biology,* Vol. 17, No. 5, (September 1990), pp. 423-435

Lehtonen-Veromaa, M.; Mottonen, T.; Irjala, K.; Nuotio, I.; Leino, A. & Viikari, J. (2000a). A 1-Year prospective study on the relationship between physical activity, markers of bone metabolism, and bone acquisition in peripubertal girls. *The Journal of Clinical Endocrinology and Metabolism,* Vol. 85, No. 10, (Oct 2000), pp. 3736-3732

Lehtonen-Veromaa, M.; Mottonen, T.; Nuotio, I.; Heinonen, O.J. & Viikari, J. (2000b). Influence of physical activity on ultrasound and dual-energy x-ray absorptiometry bone measurements in peripubertal Girls: A Cross-Sectional Study. *Calcified Tissue International,* Vol. 66, No. 4, (April 2000), pp. 248–254

Lehtonen-Veromaa, M.; Mottonen,T.; Svedstrom, E.; Hakola, P.; Heinonen, O.J. & Viikari, J. (2000c). Physical activity and bone mineral acquisition in peripubertal girls. *Scandinavian Journal of Medical Science and Sports,* Vol. 10, No. 4, (August 2000), pp. 236–243

Lester, M.E.; Uros, M.L.; Evans, R.K.; Pierce, J.R.; Spiering, B.A.; Maresh, C.M.; Hatfield, D.S.; Kraemer, W.J. & Nindl, B.C. (2009). Influence of exercise mode and osteogenic index on bone biomarker responses during short-term physical training. *Bone,* Vol. 45, No. 4, (June 2009), pp. 768-776

Linden, C.; Alwis, G.; Ahlborg, G.; Gardsell, P.; Valdimarsson, O.; Stenevi-Lundgren, S.; Besjakov, J. & Karlsson, M.K. (2007). Exercise, bone mass and bone size in prepubertal boys: one-year data from pediatric osteoporosis prevention study. *Scandinavian Journal of Medicine in Science and Sports,* Vol. 17, No. 4, (August 2006), pp. 340-347

Linden, C.; Ahlborg, G.; Besjakov, J.; Gardsell, P. & Karlsson M.K. (2006). A school-curriculum-based exercise program increases bone mineral accrual and bone size in prepubertal girls: two-year data from the pediatric osteoporosis prevention (POP) study, *Journal of bone and Mineral Research,* Vol. 21, No. 6, (May 2006), pp. 829-835

Macdonald, H.M.; Cooper, D.M. & McKay, H.A. (2009). Anterior-posterior bending strength at the tibial shaft increase with physical activity in boys: evidence for non-uniform geometric adaptation. *Osteoporosis International*, Vol. 20, No. 1, (Jan 2009), pp. 61-70

Macdonald, H.M.; Kontulainen, S.A.; Khan, K.M.; Khan, H.M. & McKay, H.A. (2007). Is a school-based physical activity intervention effective for increasing tibial bone strength in boys and girls? *Journal of Bone and Mineral Research*, Vol. 22, No. 3, (March, 2007), pp. 434-446

Macdonald, H.M.; Kontulainen, S.A.; Petit, M.A.; Beck, T.J.; Khan, K.M. & McKay, H.A. (2008). Does a novel school-based physical activity model benefit femoral neck bone strength in pre- and early pubertal children? *Osteoporosis international*, Vol. 19, No. 10, (October 2008), pp. 1445-1456

MacKelvie, K.J.; Khan, K.M. & McKay, H.A. (2002). Is there a critical period for bone response to weight-bearing exercise in children and adolescents? A systematic review. *British Journal of Sports Medicine*, Vol. 36, No. 4, (August 2002), pp. 250-257

MacKelvie, K.J.; Khan, K.M.; Petit, M.A.; Janssen, P.A. & McKay, H.A. (2003). A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomised controlled trial in girls. *Pediatrics,* Vol. 112, No. 6, (December 2003), pp. e447-e452,

MacKelvie, K.J.; McKay, H.A.; Khan, K.M. & Crocker, P.R.E. (2001). A school-based exercise intervention augments bone mineral accrual in early pubertal girls. *Journal of Pediatrics,* Vol. 139, No. 4, (October 2001), pp. 501-508

MacKelvie, K.J.; MckKay, H.A.; Petit, M.A.; Moran, O. & Khan, K.M. (2002). Bone mineral response to a 7-month randomised controlled school-based jumping intervention in 126 prepubertal boys: associations with ethnicity and body mass index. *Journal of Bone and Mineral Research,* Vol. 17, No. 5, (May 2002), pp. 834-844

MacKelvie, K.J.; Petit, M.A.; Khan, K.M.; Beck, T.J. & McKay, H.A. Bone mass and structure are enhanced following a 2-uyear randomised controlled trial of exercise in prepubertal boys. *Bone,* Vol. 34, No. 4, (December 2003), pp. 755-764

Matkovic, V.; Jelic, T.; Wardlaw, G.; Ilich, J.; Goel, P.; Wright, J.; Andon, M.B.; Smith, K.T. & Heaney, R.P. (1994). Timing of peak bone mass in Caucasian females and its implication for the prevention of osteoporosis. Inference from a cross-sectional model. *Journal of Clinical Investigation*, Vol. 93, No. 2, (February 1994), pp. 799-808

McKay, H.A.; MacLean, L.; Petit, M.; MacKelvie O'Brien, K.; Janssen, P.; Beck, T. & Khan, K.M. (2005). 'Bounce the bell': a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *British Journal of Sports Medicine,* Vo. 39, No. 8, (August 2005), pp. 521-526

McKay, H.A.; Petit, M.A.; Schutz, R.W.; Rior, J.C.; Barr, S.I. & Khan, K.M. (2000). Augmented trochanteric bone mineral density after modified physical education classes: a randomised school-based exercise intervention study in prepubescent and early pubescent children. *Journal of Pediatrics,* Vol. 136, No. 2, (February 2000), pp. 156-162

McWhannell, N.; Henaghan, J.L.; Foweather, L.; Doran, D.A.; Batterham, A.M..; Reilly, T. & Stratton, G. (2008). The effect of a 9-week physical activity programme on bone and body composition of children aged 10-11 years: an exploratory trial. *International Journal of Sports Medicine,* Vol. 29, No. 12, (December 2008), pp. 941-947

Meyer, U.; Romann, M.; Zahner, L.; Schindler, C.; Puder , J.J.; Kraenzlin, M.; Rizzoli, R. & Kriemler, S. (2011). Effect of a general school-based physical activity intervention on bone mineral content and density: a cluster-randomized controlled trial. *Bone,* Vol. 48, No. 4, (April 2011), pp. 792-797

Molgaard, C.; Thomsen, B.L. & Michaelsen, K.M. (1999). Whole body bone mineral accretion in healthy children and adolescents. *Archives of Disease in Childhood*, Vol. 81, No. 1, (July 1999), pp. 10-15

Morris, F.L.; Naughton, G.; Gibbs, J.L.; Carlson, J.S. & Wark , J.D. (1997). Prospective ten-month exercise intervention in premenarchal girls: positive effects on bone and lean mass. *Journal of Bone and Mineral Research,* Vol. 12, No. 9, (September 1997), pp. 1453-1462

Murphy, N.M.; Dhuinn, M.N.; Brown, P.A. & ORathaille, M.M. (2006). Physical activity for bone health in inactive teenage girls: is a supervised ,teacher-led program or self- led program best? *Journal of Adolescent Health*, Vol. 39, No. 4, (Oct 2006), pp. 508-514

Nemet, D.; Berger-Shermech, E.; Wolach, B. & Eliakim, A. (2006). A combined dietary-physical activity intervention affects bone strength in obese children. *International Journal of Sports Medicine,* Vol. 27, No. 8, (August 2005), pp. 666-671

Nichols, D.L.; Snaborn, C.F.; Essery E.V.; Clark R.Al & Letendre, J. (2008). Impact of curriculu-based bone loading and nutrition education program on bone accrual in children. *Pediatric Exercise Science,* Vol. 20, No. 4 (November 2008), pp. 411-425

Nichols, D.L.; Sanborn, C.F. & Love, A. (2001). Resistance training and bone mineral density in adolescent females. *Journal of Pediatrics*, Vol. 139, No. 4, (Oct 2001), pp. 494-500

Nikander, R.; Kannus, P.; Rantalainen, T.; Uusi-Rasi, K.; Heinonen, A. & Sievanen, H. (2009). Cross-sectional geometry of weight-bearing tibia in female athletes subjected to different exercise loadings. *Osteoporosis International,* Vol. 21, No. 10

Nikander, R.; Sievanen, H.; Heinonen, A.; Daly, R.M.; Uusi-Rasi, K. & Kannus, P. (2010). Targeted exercise against osteoporosis: a systematic review and meta-analysis for optimising bone strength throughout life. *BMC Medicine,* Vol. 8, No. 1, pp. 47

Petit, M.A.; McKay, H.A.; MacKelvie, K.J.; Heinonen, A.; Khan, K.M. & Beck, T.J. (2002). A randomised school-based jumping intervention confers site and maturity-specific benefits on one structural properties in girls: a hip structural analysis study. *Journal of Bone and Mineral Research,* Vol. 17, No. 3, (March 2002), pp. 363-372

Rauch, F.; Bailey, D.A.; Baxter-Jones, A.; Mirwald, R. & Faulkner R. (2004). The 'muscle-bone unit during' the pubertal growth spurt. *Bone,* Vol. 34, No. 5, (May 2004), pp. 771-75

Schoenaue, E. & Fricke, O. (2008). Mechanical influences on bone development in children. *European Journal of Endocrinology,* Vol. 159, pp. S27-S31

Scheonau, E. & Frost, H.M. (2002). The "muscle-bone unit" in children and adolescents. *Calcified Tissue International,* Vol. 70, No. 5, (April 2002), pp. 405-407

Schoenau, E.; Saggese, G.; Peter, F.; Baroncelli, B.I.; Shaw, N.J.; Crabtree, N.J.; Zadik, Z.; Neu, C.M.; Noordam, C. & Radetti, G. (2004). From bone biology to bone analysis. *Hormone Research*, Vol. 61, No. 6, (February 2004), pp. 257-269

Schneider, M.; Dunton, G.F.; Bassin, S.; Graha, D.J.; Eliakim, A.F. & Cooper, D.M. (2007). Impact of a school-based physical activity intervention on fitness and bone in adolescent females. *Journal of Physical Activity & Health,* Vol. 4, No. 1, (January 2007), pp. 17-29

Schrader, S. L.; Blue, R. & Horner, A. (2005). Better bones buddies: an osteoporosis prevention program. *The Journal of School Nursing,* Vol. 21, No. 2, (April 2005), pp. 106-114

Sharma, S.V.; Hoelscher, D.M.; Kelder, S.H.; Diamon, P.; Day, R.S. & Hergenroeder, A. (2010). Psychosocial factors influencing calcium intake and bone quality in middle school girls. *Journal of the American Dietetic Association,* Vol. 110, No. 6, (June 2010), pp. 932-936

Stager, M.; Harvey, R.; Secic, M.; Camlin-Shingler, K. & Cromer, B. (2006). Self-reported physical activity and bone mineral density in urban adolescent girls. *Journal of Pediatric and Adolescent Gynecology*, Vol. 19, No. 1, (February 2006), pp. 17-22

Stear, S.J.; Prentic, A.; Jones, S.C. & Cole, T.J. (2003). Effect of a calcium and exercise intervention on the bone mineral status of 16-18-y-old adolescent girls. *American Journal of Clinical Nutrition,* Vol. 77, No. 4, (April 2003), pp. 985-992

Stager, M.; Harvey, R.; Secic, M.; Camlin-Shingler, K. & Cromer, B. (2006). Self-reported physical activity and bone mineral density in urban adolescent girls. *Journal of Pediatric and Adolescent Gynecology*, Vol. 19, No. 1, (February 2006), pp. 17-22

Steelman, J. & Zeitler, P. (2001). Osteoporosis in pediatrics. *Pediatrics in Review,* Vol. 22, No. 2, (February 2001), pp. 56-65

Stillman, R.J.; Lohman, T.G.; Slaughter, M.H. & Massey, B.H. (1986). Physical activity and bone mineral content in women aged 30 to 85 years. *Medicine and Science in Sports and Exercise*, Vol. 18, No. 5, (October, 1986), pp. 576-580

Tanner J.M. (1962). *Growth at Adolescence*. (2nd ed). Blackwell Scientific Publications, Oxford.

Tudor-Locke, C. & R. S. McColl. (2000). Factors related to variation in premenopausal bone mineral status: a health promotion approach. *Osteoporosis International*, Vol. 11, No. 1, pp. 1-24

Turner, C.H. & Robling, A.G. (2003). Designing exercise regimens to increase bone strength. *Exercise Sport Science Review,* Vol. 31, No. 1, (September 2002), pp. 45-50

Valdimarsson, O.; Linden, C.; Johnell, O.; Gardsell, P. & Karlosson, M.K. (2006). Daily Physical Education in the school curriculum in prepubertal girls during 1 year is followed by increases in bone mineral accrual and bone width – data from the prospective controlled Malmo Pediatric Osteoporosis Prevention Study. *Calcified Tissue International,* Vol. 78, No. 2, (February 2006), pp. 65-71

Valimaki, M. J.; Karkkainen, M.; Lamberg-Allardt, C.; Laitinen, K.; Alhava, E.; Heikkinen, J.; Impivaara, O.; Makela, P.; Palmgren, J.; Seppanen, R.; Vuori, I. & the Cardiovascual Risk in Young Finns Study Group. (1994). Exercise, smoking, and calcium intake during adolescence and early adulthood as determinants of peak bone mass. *British Medical Journal*, Vol. 309, (July 1994), pp. 230-235

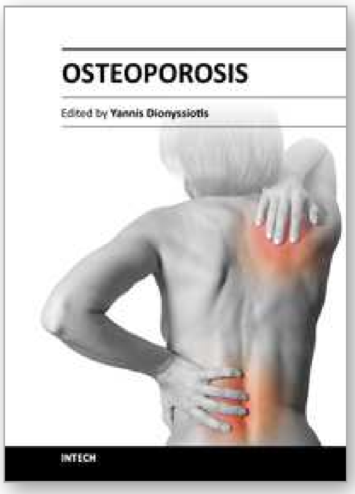
Van Langendonck, L.; Classens, A.L.; Vleintinck, R.; Derom, C. & Beunen, G. (2003). Influence of weight-bear exercises on bone acquisition in prepubertal monozygotic female twins: a randomised controlled prospective study. *Calcified Tissue International,* Vol. 72, No. 6, (June 2003), pp. 666-674

Wallace, L.S. (2002). Osteoporosis prevention in college women: application of the expanded health belief model. *American Journal of Health Behavior*, Vol. 26, No. 3, (May 2002), pp. 163-172

Weeks, B.K.; Young, C.M. & Beck, B.R. (2008). Eight months of regular in-school jumping improves indices of bone strength in adolescent boys and girls: the POWER PE study. *Journal of Bone and Mineral Research,* Vol. 13, No. 7, (Feb 2008), pp. 1002-1011

Witzke, K.A. & Snow, C.M. (2000). Effects of plyometric jump training on bone mass in adolescent girls. *Medicine and Science in Sports and Exercise,* Vol. 32, No. 6, (June 2000), pp. 1051-1057

Wyshak, G. & Frisch, R.E. (1994). Carbonated beverages, dietary calcium, the dietary calcium/phosphorus ratio, and bone fractures in boys and girls. *Journal of Adolescent Health,* Vol. 15, No. 3, (May 1994), pp. 210-215



Osteoporosis

Edited by PhD. Yannis Dionyssiotis

ISBN 978-953-51-0026-3
Hard cover, 864 pages
Publisher InTech
Published online 24, February, 2012
Published in print edition February, 2012

Osteoporosis is a public health issue worldwide. During the last few years, progress has been made concerning the knowledge of the pathophysiological mechanism of the disease. Sophisticated technologies have added important information in bone mineral density measurements and, additionally, geometrical and mechanical properties of bone. New bone indices have been developed from biochemical and hormonal measurements in order to investigate bone metabolism. Although it is clear that drugs are an essential element of the therapy, beyond medication there are other interventions in the management of the disease. Prevention of osteoporosis starts in young ages and continues during aging in order to prevent fractures associated with impaired quality of life, physical decline, mortality, and high cost for the health system. A number of different specialties are holding the scientific knowledge in osteoporosis. For this reason, we have collected papers from scientific departments all over the world for this book. The book includes up-to-date information about basics of bones, epidemiological data, diagnosis and assessment of osteoporosis, secondary osteoporosis, pediatric issues, prevention and treatment strategies, and research papers from osteoporotic fields.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821