THE EFFECTS OF DIFFERENT TRAINING MODALITIES ON BONE MASS: A REVIEW

Cvita Gregov and Sanja Šalaj

Faculty of Kinesiology, University of Zagreb, Croatia

Review

Abstract:

It is evident that there are a large number of studies dealing with the problem of osteoporosis due to the exponential growth of fracture occurrence in elderly population. The risk for fracture is closely related to the natural loss of bone mass in women and men as a result of aging. Due to obvious demographic changes in age, i.e. an overall process of population aging, the number of fractures is higher than expected, which indicates that bone quality is deteriorating from one generation to the next. In order to prevent the deterioration it is necessary to come up with appropriate prophylactic and therapeutic methods. Apart from standard methods comprising of calcium and vitamin D supplementation, which do not have a great effect on bone, one of the best non-pharmacological methods for lifelong improvement of bone mass is physical exercise, or participation in quality training, as evidenced by number of studies. Of course, practical work and scientific research indicate that not all exercise modalities are equally efficient in improving bone mass, i.e. there are modalities that can significantly affect the bone quality and there are those that do not have a notable influence on the same. Therefore, it is necessary to determine the most efficient physical exercise modalities for improving bone mass quality in different age groups through inspection of previous studies. The importance of physical activity in enhancing bone quality, i.e. increasing bone mass and strength, is evidenced by a number of studies showing positive effects of sport and various types of training on above-mentioned properties. This is supported by results of the studies indicating that training is potentially superior to supplementation of essential minerals for metabolism and bone mass. Regarding the type of training, or type of physical activity with the highest potential for increasing bone mass, there are two activities that stand out – work-outs with great loadings and jump exercises, that is, strength training and plyometric training. Another type of training focused on increasing bone mass that is becoming prominent lately is vibration training, but compared to other two, which are more appropriate for young population due to its simplicity and safety, it is appropriate for elderly population. Aerobic training significantly affects cardiovascular health and shows certain indications of improving or at least maintaining bone mass. Therefore, if we want to maintain optimal bone mass throughout life, it is beneficial to participate in systematic sports training from early childhood and to regularly involve oneself in physical activities on a regular basis over longer periods of time, especially in those creating greater ground reaction forces and in those with external loading larger than those of everyday life. It is a challenging task to give a valid conclusion about optimal loading parameters for specific types of training due to inconsistency in methodological approaches and, often, controversial findings. Hence, future research should focus on: a) the determination of optimal loading parameters for specific types of training and age groups with a uniform methodology; b) topological effects of specific exercises, especially in strength and jump training; c) the determination of effects of agility training as a potential protocol for bone mass development in young population; and d) the determination of residual effects of training focused on bone mass gains, that is, the on effects of detraining.

Key words: *bone mineral density, osteoporosis, exercise, strength, plyometrics*

Introduction

There is a large number of studies dealing with the problem of osteoporosis, probably due to the exponential growth of fracture incidence in elderly population (Riggs & Melton, 1995). The risk for fracture is closely related to the natural age-induced loss of bone mass in women and men (Gomez-Cabello, et al., 2012). Despite of the more than obvious demographic changes in age, i.e. a process of the overall population getting ever older, the actual number of fractures is higher than the expected one, which indicates that bone quality is deteriorating from one generation to the next (Wolff, et al., 1999).

In order to prevent the deterioration it is necessary to come up with appropriate prophylactic and therapeutic methods. Apart from the standard methods consisting of calcium and vitamin D supplementation, which do not have a great effect on bone density (Jackson, et al., 2006), one of the best non-pharmacological methods for lifelong improvement of bone mass is physical exercise, or participation in quality training, as evidenced by quite a number of studies (Vincente-Rodriguez, 2006).

Of course, practical work and scientific research indicate that not all modalities of exercising are equally efficient in improving bone mass, i.e. there are modalities that can significantly affect bone quality and there are those that do not have that specific notable influence on the same.

Therefore, the main objective of this study was to determine those modalities of physical exercise, or training, that were found the most efficient in improving bone mass in different age groups. The objective will be accomplished through the inspection of previous research studies.

Bone adaptation

Bones, like any other organic system, have a great ability to adapt to various external stimuli, especially important of which are the mechanical ones. They refer to a variety of loading, from small ones, as for example the gravitation, to large ones like great impact force, for example the ground reaction force. These mechanical stimuli affect the metabolism of bone cells *in vitro*, and manifest as shear fluid stress, tension and compression stress, altered gravitation and vibration (Scott, et al., 2008).

According to Harold Frost's *mechanostat theory*, bone structure and strength must be able to endure the typical maximal mechanical loading of everyday life, in order to avoid sudden fractures during high-stress activities (Frost, 2003). The premise of this hypothesis is that bone mass changes when typical loading conditions (which lead to strain of the bone tissue) differ from the physiological stimuli threshold (1000 to 1500 micro strain or 1 to 1.5%). In order to induce structural modification of bones, speed and magnitude of strain, the main signals for the adaptation of bones to mechanical loading, must reach the previously mentioned minimal levels. With the intention of improving bone mass or bone density in physically inactive population, the bone tissue must be put under the loadings greater than those of everyday activities (Guadalupe-Grau, et al., 2009). The signal paths between mechanical loading and bone formation are not entirely identified, however we definitely know that mechanical loading stimulates proliferation of osteoblasts necessary for bone adaptation (Scott, et al., 2008).

Therefore, bone formation in healthy people, except from being conditioned by a) *system factors* (cytokines, growth factors, metabolites, endocrine and neuroendocrine signals), primarily reacts to b) *previous mechanical loading* (Scott, et al., 2008). Precisely, that mechanical loading is present during performance in various sport activities, that is during sport-specific training and, consequently, training contents and overall loading.

Active athletes and bone mass quality

Given that physical activity represents a mechanical stimulus for human organism, or human skeletal system, sport and sport training, which embraces physical activities of great intensity and volume, certainly have a great osteogenetic potential. This has been proved in a number of studies that record greater bone mass in athletes and former athletes than in the untrained population (Arasheben, et al., 2011).

Nikander et al. (2006) showed in their analysis of bone mass of athletes in various sports that athletes participating in high- and odd-impact sports had a greater bone strength compared to athletes participating in low-impact sports. This means that high strains, produced during dynamic and unusual movements to various directions, improve osteogenesis and distribution of bone mass (Nikander, et al., 2006; Dias Quiterio, et al., 2011). Dias Quiterio et al. (2011) came to the same conclusion working with young athletes, mostly gymnasts, basketball and handball players, in whom greater bone mass was recorded compared to swimmers.

Table 1 shows the relationship between various sports and differences in bone mass, respectively. The overview of these studies shows that sports like football, tennis, rugby, netball and running present a greater mechanical stimulus and, consequently, a greater stimulus for bone mass adaptation.

The effect of strength training on bone mass

Common conclusions of transversal studies is that exercise modalities during which great forces are generated and/or which lead to greater ground reaction forces have the highest osteogenic impact (Guadalupe-Grau, et al., 2009). Strength training is one type of exercise modalities whose goal is to produce as much force as possible and therefore has potentially great effect on osteogenesis, or improving bone quality and preventing fractures in older population.

Furthermore, strength training is one of the most widely used training protocols in studies investigating the effect of physical exercise on bone mass improvements in younger and older population, that is, it has a significant osteogenic effect in both groups (Table 2).

Some studies of strength-trained young female athletes, however, have not reported changes in bone adaptation (Sinaki, et al., 1996; Chilibeck, et al., 1996; Nindl, et al., 2000) regardless of protocol duration and a relatively great loading. On a closer inspection it becomes evident that the common factor of these studies is a small variability of

Table 1. Athletes in various sports and differences in bone mass (according to Guadalupe Grau, et al., 2009)

Study	Sport	Average duration of training	Participants' sport experience (years on average)	Participants' age (year)	Differences in bone mass compared to the control group* (BMD and BMC)
Young men					
Calbet et al. (2001)	Football	7 hours/w.	12	19-27	↑ 10-27% BMD ↑13-24% BMC
Morel et al. (2001)	Running, Rugby, Martial arts Body-building Swimming	8.1 hours/w 8.7 hours/w 9.1 hours/w 8.1 hours/w 8.7 hours/w	22 15 18 16 11	25-40	↑1-10% BMD ↓5% BMD Body-building ↓ 8% BMD Swimming (compared to the other sports)
Calbet et al. (1998)	Tennis	25 hours/w	17	21-32	↑ 10-15% BMD ↑ 5 % BMC
Wittich et al. (1998)	Football	20 hours/w	8	20-24	↑ 11-14% BMD ↑ 15-25% BMC
Young women					
Egan et al. (2006)	Running, Rugby, Netball	8.4 hours/w 4.1 hours/w 3.7 hours/w	9 4 4	19-23	↑ BMD
Nichols et al. (2007)	Football, Volleyball, Softball, Tennis, Lacrosse,	8.6 hours/w	6.5	14-16	↑ BMD in eumenorrheic female athletes compared to amenorrheic ↑ BMD in eumenorrheic female athletes (N, O, S, T, L) compared to amenorrheic (T, P)
	Running, Swimming	8.5 hours/w	6.1		
Alfredson et al. (1996)	Football	6 hours/w	-	18-27	↑ 10.7-19.6% BMD
Ducher et al. (2004)	Tennis	3 hours/w	14	20-25	↑ 4.8% BMD ↑13.3-15.6% BMC

* In some studies the control group was comprised of untrained population, in others of athletes from other sports, and in tennis sometimes of athletes with a contralateral hand; ↑ higher scores ↓ lower scores; BMC - bone mineral content; BMD - bone mineral density; w – week.

training concerning the number of exercises. Namely, studies on animals suggest that unusual arrangement of high-speed and high-intensity loading has a great osteogenetic potential already after very small training cycles (Wolf, et al., 1999).

Moreover, Table 2 clearly shows that strength training produces smaller total effects in older population, especially women. To be precise, a smaller number of estrogenic receptors, which is a characteristic of postmenopausal women, results in a lower osteogenic potential. This is also the case with women during amenorrhea or after ovary renoval (Guadalupe-Grau, et al., 2009).

In older age it is especially important to implement greater loadds with fewer repetitions, as recommended by Kerr et al. (1996) who proved that training with a greater loading and a smaller number of repetitions has a higher effect on improving bone mineral density of the hip and forearm than more frequent sessions with a smaller load. This was confirmed by Maddalozzo et al. (2000).

As for the effects of eccentric strength training versus concentric training, the results clearly show the superiority of eccentric strength training method in bone mass adaptation (Hawkins, et al., 1999; Schroeder, et al., 2004; Nickols-Richardson, et al., 2007), although it is interesting to point out that Schroeder et al. (2004) reported better results achieved with the eccentric strength training method with a smaller loading (75% 1 RM) compared to greater loading (125% 1RM). The difference between the first two studies and that of Schroeder is that they used isokinetic method of eccentric training, while Schroeder used isoinertial method.

Taking everything into account, Table 2 shows that by participating in training the modality of which requires overcoming the external loading, person's bone mass can be improved or at least its loss, which occurs after menopause or in older age, can be moderated.

In order to achieve this, a strength training program should implement a greater external loading (60-85% 1 RM), a large variety of contents, i.e. exercises, and it should last the minimum 6 months with no interruptions. Furthermore, present scientific studies suggest that increase in bone mass is related to the topological region of the body activated in specific exercise performance (Iida, et al., 2012). Thus, among other things, based on our knowledge of bone growth mechanisms, we can assume that training operators should be made up in such a way that they "put eccentric and concentric loading on muscle insertion, i.e. that region where we wish to induce the highest effect in acquiring bone mass".

Table 2. The effects of strength training on bone mass

Study	Participants (number, gender and age)	Training/exercise modality	Loading (training intensity and volume)	Duration of the program (months/m or weeks/w)	Program effects
Young and premenopausal women					
Lohman et al. (1995)	n=22 f 28-39 yrs	Strength exercises with loading on the upper (7) and lower(3) extremities	3 d/w 3 sets x 8-12 reps 75-80% 1 RM	18 months	↑
Sinaki et al. (1996)	n=60 f 30-40 yrs	Strength exercises with loading on the upper extremities and back	3 d/w 3 sets x 10 reps 50-100% 10 RM	36 months	↔
Chilibeck et al. (1996)	n=20 f 19-21 yrs	Strength exercises with loading on the upper (2) and lower(1) extremities + endurance training	2 d/w	4.5 months	↔
Hawkins et al. (1999)	n=16 f 19-23 yrs	Concentric and eccentric isokinetic flexion and extension in the knee	3 d/w a) conc: 3 reps x 4 reps 1 RM b) eccen: 3 sets x 3 reps 1 RM	4.5 months	↑ in a group b) eccen
Nindl et al. (2000)	n=26 f 24-32 yrs	Strength exercises with loading on the upper (2) and lower(2) extremities and abdomen + aerobics	5 d/w 4-6 sets x 10-12 reps	6 months	↔
Schroeder et al. (2004)	n=28 f (14+14) 22-26 yrs	Eccentric strength exercises with loading on the lower (4) and upper (4) extremities	2 d/w 3 sets x 10 reps a) 125% 1RM b) 75% 1RM	4 months	↑ in a group b) 75%1RM
Winters-Stone i Snow (2006)	n=35 f 34-44 yrs	Strength exercises with loading on the upper (7) and lower (3) extremities. + jumps	3 d/w 3-9 sets x 8-12 reps ↑ 0-13% body weight	12 months	↑
Nickols-Richardson et al. (2007)	n=70 f 18-26 yrs	Unilateral concentric and eccentric isokinetic legs and arms' training	3 d/w 1-3 sets x 6 reps till exhaustion	5 months	↑ In both groups
Older women					
Pruitt et al. (1992)	n=35 f 60-70 yrs	Strength exercises for the lower extremities (6), upper (4) and back (1)	3 x w 1 x 10-15 reps 10-15 RM	9 months	Exp ↓ Con
Nelson et al. (1994)	n=20 f 50-70 yrs	Strength exercises with loading (5)	2xw 3 x 8 reps 80%1RM	12 months	↑ Exp ↓Con
Kerr et al. (1996)	n=56 f(a28+b28) 40-70 yrs	Strength exercises with loading on the lower (4) and upper extremities (5) a) 3 x 8 RM b) 3 x 20 RM	3 x w a) 3 x 8 RM 60%RM legs 40%RM arms b) 3 x 20 RM 20% RM legs 10% RM arms	12 months	↑ a in all points ↑ b just in radius
Kohrt et al. (1997)	60-74 yrs	Strength exercises with loading on the lower (4) and upper extremities (4)	3 x w 2-3 x 8-12 8-12 RM	11months	↑

Ryan et al. (1998)	n=27 f 60-63 yrs	Strength exercises with loading on the lower (4) and upper (5) extremities and torso (1)	Lower: 2 x 12-15 reps Upper: 1 x 3 RM 3 x w	16 w	↔
Adami et al. (1999)	n=118 f 59-710 yrs	Strength exercises with loading on the upper extremities	2 x w + 30min a day at home	6 months	↔ and ↓
Taaffe et al. (1999)	n=34 f 65-79 yrs	Strength exercises with loading on the lower (3) and upper (3) extremities and back (1)	3 x 8 reps 80% 1RM 1-3 x w	24 w	↔
Maddalozzo et al. (2000)	n=18 f (9+9) 50-60 yrs	Strength exercises with loading on the upper and lower extremities a) moderate intensity b) high intensity	3 x w a) 3x10 reps 40-60% 1RM b) 3x2-10 reps 70-90% 1RM	6 months	↑ high-intensity group
Bunout et al. (2001)	n=73 m/f 71-78 yrs	Strength exercises with loading on the lower (2) and upper extremities (1) relatively	2 x w	18 months	↓ (slightly less than in con)
Kerr et al. (2001)	n=84 f 55-65 yrs	Strength exercises with loading on the lower (2) and upper extremities (5)	3 x w 3 x 8 RM	24 months	↑
Liu-Ambrose et al. (2004)	n=66 f 75-85 yrs	Strength exercises with loading on the lower and upper extremities and torso	2 x 10-15 reps 2 x 6-8 reps 50-60 to 75-85% 1RM 2 x w	25 w	↑
Verschueren et al. (2004)	n=22 f 34-44 yrs	Strength exercises with loading on the lower extremities (2)	3 x w 1-3 s x 10-15 reps 20-8 RM	6 months	↔ ecc ↔ con
Stengel et al. (2005)	n=42 f 54-60 yrs	1) Strength exercises with loading 2) Exercises for explosive power + vitamin Ca and D supplementation	4x w 70-90%1RM	12 months	↔ group 1 ↓ group 2
Stewart et al. (2005)	n=26 f 55-75 yrs	Strength exercises with loading on the lower (3) and upper extremities (4) and torso	3 x w 2x10-15 reps	6 months	↔
Daly et al. (2005)	n=6 m/f 60-80 yrs	Strength exercises with loading on the lower (1) and upper (6) extremities and torso (1)	3 x w	12 months (6 + 6 at home)	↔ (after 6 and 12 months) ↓ con
Brentano et al. (2008)	n=18 f	1) strength training with loading 2) circular strength training with loading	1) 45-80% 1 RM, 2-4 sets, 20-6 reps 2) 45-60% 1 RM, 2-3 sets, 20-10 reps	24 w	↔
Fjelstad et al. (2009)	n=22 f 63-64.8 yrs	Strength exercises with loading on the lower (5) and upper extremities (3)	3 x w 3 x 10 reps 80%1 RM	8 months	↓
Bocalini et al. (2009)	n=15 57-75 yrs	Strength exercises with loading on the lower (5) and upper (6) extremities and torso (1)	50-85% 1 RM 3xw	24 w	↔ ↓ con
De Matos et al. (2009)	n=30 f 45-65 yrs	Strength exercises with loading on the lower (7) and upper extremities (3)	1-4 kg	12 months	↔ ↓ con

Marques et al. (2011)	n=24 f 6–95 yrs rct	Strength exercises with loading on the lower (4) and upper extremities, and torso (4).	3 x w 2 x 10-15 reps From 50-60% to 70-85% 1 RM	8 months	↑ ↔
Young men					
Fujimura et al. (1997)	n=8 f 23-31 yrs	Strength exercises with loading on the lower (3) and upper extremities and torso (7)	3 x w 2-3 x 10 reps 60-80% 1 RM	4 months	↔
Ryan et al. (2004)	n=42 m/f 20-29 yrs 65-74 yrs	Strength exercises with loading on the lower (3) and upper extremities and torso (8)	3 x w 2 sets till exertion 12-15 RM	6 months	↑ in the whole sample
Ballard et al. (2006)	n=25 (13m+12f) 20-22 yrs	Strength exercises with loading on the lower (3) and upper extremities and torso(7) + aerobics	5 d/w 3 sets x 12 RM (failure rep) 70% 1RM; 70%VO_{2max}	6 months	↑ at m and w
Hartman et al. (2007)	n=37 f 18-30 yrs	Strength exercises with loading on the lower (4) and upper extremities and torso (9) + supplementation a) soya, b) milk	5 x w 2-4 x 4-12 reps 80% 1 RM	3 months	↔
Middle aged and older men					
Menkes et al. (1993)	n=11m 54-61 yrs	Strength exercises with loading on the lower (2) and upper extremities and torso (4)	3-5 x w 1-2 x 15 reps 5-15 RM	4 months	↑
Ryan et al. (1994)	n=21 m 51-71 yrs	Strength exercises with loading on the lower (5) and upper extremities and torso (8)	3 x w 2 x15 reps 5 RM	4 months	↑
Maddalozzo et al. (2000)	n=24 m (12+12) 50-60 yrs	Strength exercises with loading on the upper and lower extremities a) moderate intensity b) high intensity	3 x w a) 3 x 10-13 reps 40-60% 1 RM b) 3 x 2-10 reps 70-90% 1 RM	6 months	↑ a and b
Bunout et al. (2001)	n=73 m/f 71-78 yrs	Strength exercises with loading on the lower (2) and upper extremities (1) Relatively	2 x w	18 months	↓ (slightly less than in con)
Daly et al. (2005)	n=6 m/f 60-80 yrs	Strength exercises with loading on the lower (1) and upper (6) extremities and torso (1)	3 x w	12 months (6 + 6 at home)	↔ (after 6 and 12 months) ↓ con
Stewart et al. (2005)	n=26 m 55-75 yrs	Strength exercises with loading on the lower (3) and upper extremities and torso (4)	3 x w 2 x 10-15 reps	6 months	↑
Whiteford et al. (2010)	n=57 m 58-70 yrs	Strength exercises with loading on the lower (4) and upper extremities (5)	3 x w 3 x 8 reps 8 RM	12 months	↔
Alcaraz et al. (2011)	n=33 m	High-intensity strength training a) with short break of 35 s b) with long break of 3 min	3 x w 3-6 sets, 6 exercises, 6 RM	8 weeks	↔

*n - number of participants in experimental group or in more of them; ↑ significant increase; ↔ no changes; ↓ significant decrease; m - male; f - female.

The effects of plyometric training on bone mass

Apart from strength training, the greatest effects on bone formation are attributed to plyometric training (Gaudalupe-Grau, et al., 2009). Plyometric training is a type of training that consists of jumping and throwing exercises with focus on stretch-shortening cycle (SSC) during which the body experiences great ground reaction forces (even seven times bigger than body weight) (Marković & Mikulić, 2010); SSC entails high-intensity eccentric contractions immediately before fast and powerful concentric contraction.

Hence, the lower body exercises are various jumps without loading (depth jumps, counter-movement jumps, single leg sporadic jumps, skipping and similar), and exercises for the upper body are: push-ups, medicine ball throws, plyometric push-ups and similar.

Plyometric training exercises are designed to develop explosive jumping power and increase speed and power in general. Since plyometric training entails a great impact loading as the before mentioned ground reaction forces, it represents one of the potentially most valued training modality for improving bone mass.

The purpose of plyometric studies was to improve bone mass over time periods of 9 weeks (Witzke & Snow, 2000) up to 48 months (Löfgren, et al., 2012), but in most cases the studies lasted 7 to 20 months; usually with 50-100 jumps per session, 3 to 5 training sessions per week (Table 3). Also, femoral neck recorded the greatest improvement compared to the other measured skeletal regions like lumbar spine, trochanter, or proximal part of the femur (Marković & Mikulić, 2010).

As shown in Table 3, postmenopausal women and older population in general were considerably under-represented in the studies. The fact leaves space and offers guidelines for the future studies.

Namely, the greatest effects of plyometric trainings were recorded in early adolescent children compared to prepubertal and, especially, pubertal children (Table 3). The respected study by Gunter et al. (2008) drew attention to the fact that positive effects of a seven-month plyometric training were maintained in prepubertal children on higher levels up to 7 years after the training compared to the untrained children. In other words, plyometric activities in early childhood influence the long-term increase of bone mass that surpasses the effects of normal development and growth.

Great loading conditions, imposed by jump training or plyometric training, are probably reason for its small, if any, application to the older population. However, this does not mean that we should exclude activities like skipping, jumping, rope skipping and similar from the training protocol for older population, especially postmenopausal women. There is a certain number of studies investigating the effects of multipurpose training on older population, which included, among others, various jumping and skipping exercises (Welsh, et al., 1996; Karikanta, et al., 2007; Tolomio, et al., 2008) that led to positive changes in bone mass or at least to the reduced deterioration compared to the control groups.

Table 3. The effects of plyometric training on bone mass

Study	Participants (number, gender and age)	Training/exercise modality	Loading (training intensity and volume)	Duration of the program (months/m or weeks/w)	Program effects
Prepubertal and pubertal children					
Heionen et al. (2000)	a) n=25 f pre-menarhe b) n=64 f post-menarhe	Combined aerobic jump and running training	2 x w 100-200 jumps	9 m	↑a ↑b (significantly higher effects in group a)
Fuchs et al. (2001)	n=55 m/f prepuberty	Jumps	3 x w 50-100 jumps	7 m	↑
MacKelvie et al. (2001)	a) n=44 f prepuberty b) n=43 early puberty	Jumps	3 x w 50-100 jumps	7 m	↔a ↑b
MacKelvie et al. (2002)	n=61m prepuberty	Jumps	3 x w 50-100 jumps	7 m	↑
Petit et al. (2002)	a) n=44 f prepuberty b) n=43 f early puberty	Jumps	3 x w 50-100	7 m	↔a ↑b

Iuliano-Burns et al. (2003)	a) n=18 f prepuberty and early puberty	Jumps	3 x w	8.5 m	↔ ↑
Johannsen et al. (2003)	n=28 m/f 3-18 yrs	Jumps	5 x w 25 jumps	12 w	↔ ↑
MacKelvie et al. (2003)	n=32 f 9.9 yrs	Jumps	3 x w 50-132 jumps	20 m	↔ ↑
MacKelvie et al. (2004)	n=31 m prepuberty and early puberty	Jumps	3 x w 50-132 jumps	20 m	↔ ↑
McKay et al. (2005)	n=51 m/f 10.1 yrs	Counter movement jumps (CM)	3 x w 10 jumps	8 m	↔ ↑ (decrease of total BMC and BA)
Gunter et al. (2008)	n=101 m/f	Jumps	3 x w ~100	7 m	↑
Löfgren et al. (2012)	n= 908 m/f 7-9 yrs	Jumping, Running, Climbing (PE lesson)	7x40 min/w (i.e. daily) con (1 PE class w)	48 m	↑ BMC higher in exp
Young and premenopausal women					
Bassey and Ramsdale (1994)	n=14 f	Counter-movement jumps (CM)	5 d/w	6 m	↑ ↔
Bassey et al. (1998)	a) n=33 f premenopausal b) n=69 f postmenopausal	Counter-movement jumps (CM)	6 x w 50 jumps	a) 6 m premenopausal b) 12 m postmenopausal	↑ a ↔b
Witzke and Snow (2000)	a) n=25 f adolescents	Plyometric training + strength training with loading	3 x w	9 m	↔
Vainionpää et al. 2005)	n=39 f premenopausal women	Jumps combined with walking, running and stamping	3 x w	12 m	↑
Kato et al. (2006)	n=18 f 20.7 yrs	Counter-movement jumps (CM)	3 x w 10 jumps	6 m	↑
Weeks et al. (2008)	n=43 m/f adolescents	Jumps	2 x w ~300 jumps	8 m	↑
Bailey and Brooke-Wavell (2010)	n=61 f premenopausal 33.6±11.1 yrs	Unilateral multidirectional jumps 2.5 - 2.8 tt - peak ground reaction force	0 x w 2 x w 4 x w 7 x w 50 jumps	6 m	↑just in d
Guadalupe-Grau et al. (2009)	n=28 m/f	Plyometric training combined with weightlifting	3 x w 40-70 jumps	9 w	↔ ↑

*n - number of participants in experimental group or in more of them; ↑significant increase; ↔no change; ↓significant fall ; m - male; f - female.

The effects of aerobic training on bone mass

Aerobic training is a type of endurance training that involves cyclic exercises through an extended period of time with no additional loading or with a very little external loading. Its main goal is to improve the capacity and performance of respiratory and cardiovascular system. One of the most essential adaptations to aerobic endurance training and one of the important indicators of healthy cardiovascular system is maximal oxygen consumption (VO_{2max}) (Åstrand, et al., 2003). That is why aerobic training is probably the most important type of training for elderly population.

Examples of typical aerobic exercises are walking, jogging, running, cycling, rowing, climbing stairs and similar. All these exercises are of a relatively low intensity, i.e. small mechanical stimuli to musclus, so their effect on bone mass is not significant. However, if we take into account that, for example, running or rope skipping produces impact forces, that is greater ground reaction forces, we can expect some positive effects on bone mass quality also. Since aerobic training is available and suitable for elderly population and, of course, of great importance for healthy cardiovascular system, a certain number of studies have been carried out in order to determine its effects on bone mass of the participants.

Thus, Table 4 does show small effects of aerobic training after all, if not on improving, then at least on maintaining bone mass in elderly people (Dalsky, et al., 1988; Blumenthal, et al., 1991; Nelson, et al., 1991; Martin & Notelovicz, 1993; Kohrt, et al., 1997; Ebrahim, et al., 1997; Chien, et al., 2000; Yamazaki, et al., 2004; Evans, et al., 2007; Irwin, et al., 2009; Silverman, et al., 2009; Yoo, et al., 2010; Marques, et al., 2011; Liang, et al., 2011). Interestingly, the training protocol of a large number of these studies included, not only climbing and jogging exercises, but also walking which helped to improve and maintain bone mass even when it was the only exercise of the training protocol (Martin & Notelovicz, 1993; Hatori, et al., 1993; Yamazaki, et al., 2004; Silverman, et al., 2009).

The importance of intensity in endurance training was publicised by Hatori et al. (1993) who compared the effects of seven-month walking above and below the aerobic threshold on bone mineral density of the lumbar spine. The group that performed the exercise below the aerobic threshold reported similar results to the control group, while the group that walked at heart rate above the aerobic threshold showed a moderate improvement of bone mineral density of the lumbar spine.

To conclude, due to small impact loading of the aerobic training programs most of the above-mentioned studies did not elicit improvement of bone mass after the application of aerobic training protocols. But given that aerobic training led to maintaining and/or reducing the loss of bone mass, we should take this type of training into consideration when programing interventions focused on maintaining bone quality in elderly people, especially through exercises like jogging and climbing.

Table 4. The effects of aerobic training programs on bone mass

Study	Participants (number, gender and age)	Modality of training/ exercise	Loading (training intensity and volume)	Duration of the program (months/m or weeks/w)	Program effects
Dalsky et al. (1988)	n=35 f 55-70 yrs	Walking, jogging, climbing stairs	3 x w 50-60 min 70-90%VO_{2max}	9 m 22 m	↑ after 9 and 22 m (highest increase after 9)
Cavanaugh & Cann (1988)	n=8 f 49-64 yrs	Walking	3 x w 15-40 min 60-85% HR_{max}	52 w	↓ in experimental and control group
Blumenthal et al. (1991)	n=33 m/f 60-83 yrs	Cycling + fast walking + wrist ergometer	3 x w 15-40 min 70% of cardiac reserve	16 w	↔
Nelson et al. (1991)	n=18 f 54.4-66.7 yrs	Walking with waistband (3.1. kg)	4 x w 75-80% HR_{max}	12 m	↑
Martin & Notelovicz (1993)	a) n=20 f b) n=16 f 51.2-65.8 yrs	Walking a) 1:30 min b) 2:45 min	3 x w 70-85% HR_{max}	12 m	↔
Hatori et al. (1993)	a) n=12 f b) n=9 f 45-67 yrs	Walking 30 min	3 x w 30 min a) HR above anaerobic threshold b) HR below anaerobic threshold	7 m	↑ a ↓ b and control group
Ebrahim et al. (1997)	n=49 f 66.4 yrs	Fast walking 40 min	3 x w 40 min Walking faster than normal, but not to cause shortness of breath	12 m 24 m	↔
Kohrt et al. (1997)	60-74 yrs f	Walking, jogging and climbing stairs	3 x w 40-45 min 60-85% HR_{max}	11m	↑

Ryan et al. (1998)	n=15 f 56-68 yrs	Walking or jogging 35 min	3 x w 35 min 50-60 to >70% VO_{2max}	6 m	↓ (similar as in the control group)
Chien et al. (2000)	n=22 f 48-65 yrs	Walking on treadmill + exercises with one step climbing	3 x w 70-85% VO_{2max}	6 m	↑ exs
Huuskonen et al. (2001)	n=70 m 50-60 yrs	Fast walking	3-5 x w 30-60 min 40-60% VO_{2max}	48 m	↓
Yamazaki et al. (2004)	n=27 f 61.3-67.1 yrs	≥1 hour of walking	At least 4 x w ≥1 hour 50% VO_{2max}	12 m	↑
Evans et al. (2007)	a) n=11 f b) n=10 f 57-67 yrs	treadmill, rowing and climbing stairs + supplementation a) soy protein isolate b) milk protein isolate	3 x w 45 min 55-60% to 75-80% VO_{2max}	9 m	↔
Irwin et al. (2009)	n=37 f 56 yrs	Walking 150 min/week	5 x w 150min/w 50 do 60-80% HR_{max}	6 m	↔
Silverman et al. (2009)	n=46 f 50-70 yrs	Walking	3 x w 45-60 min 50-75% of cardiac reserve	6 m	↑ ↔
Lovelady et al. (2009)	n=10 f 4-20 weeks after giving birth (lactation period with 3-9% loss in BMD)	Aerobic training + loading exercises	3 x w + 3 x w	16 w	↓ significantly smaller decrease than in C ↔
Yoo et al. (2010)	n=21 older women (E11+K10)	Walking with weights around ankles		3 m	↔
Marques et al. (2011)	n=24 f 60–95 yrs	Walking, jogging, dancing, aerobics, stamping	3 x w 50-60% to 65-85% of cardiac reserve	8 m	↔
Liang et al. (2011)	51 f (15+16+20) (20-35 yrs)	1) High-impact step aerobics 2) moderate intensity strength training for the lower body	12 m		↔ ↑ just in group A in BMD of heel bone

↑ Significant increase; ↔ no change; ↓ significant decrease; m - male; f - female

The effects of vibration training on bone mass

Vibration training is a type of training that uses vibration platforms, or plates, which normally vibrate at frequencies ranging from 12 to 60 hertz (Hz) with vertical change/amplitude from 0.7 to 11 mm causing magnitude/gravitational acceleration from 0.2 to 10 G (1 G=9.8 ms^{-2}) usually oriented vertically (Russo, et al., 2003; Gusi, et al., 2006; Rehn, et al., 2008; Von Stengel, et al., 2011). Vibration frequency produced by a vibration platform generates mechanical stimulus, or loading, which spreads through the body and stimulates sensor receptors (Gomez-Cabello, et al., 2012).

Immediate effects of this type of training enhance performance in jumps, sprints and different measures of muscle performance evaluation. It is less effective with trained athletes, but when used with untrained person or sedentary population, the effects are significantly better and it can replace traditional modalities of strength training.

Vibration training has positive effects on bone mineral density as well (Dolny & Reyes, 2008; Prioreschi, et al., 2012). Most longitudinal studies researching the effect of vibration training on bone mass and density recorded statistically significant improvement (Table 4).

It is difficult to determine optimal parameters as a recommendation in training for the prevention of bone mass loss due to the differences in methodological approach, i.e. tested protocols composed of different loading parameters (frequency and amplitude) and types of the applied protocols (rotation-al and vertical shift; standing on the platform and exercise performance) (Von Stengel, et al., 2011). Namely, current research dealt with protocols lasting from 6 to 18 months, weekly frequencies from 1 per week to 2 times a day and time spent in training from 4 to 20 minutes.

We highly recommend that focus of future research should be on determining the optimal loading parameters in vibration training: amplitudes, frequencies, types of vibration training and number and duration of applied training protocols.

Considering positive effects of vibration training on bone mass improvement and specific demands of older population, we can say this type of training represents a safe alternative to plyometric and strength training in the prevention of bone mass loss, especially in elderly population with mobility impairments.

Table 5. The effects of vibration training program on bone mass

Study	Participants (number, gender and age)	Modality of training/ exercise	Loading (training intensity and volume)	Duration of the program (months/m or weeks/w)	Program effects
Russo et al. (2003)	n=14 f 54.6-66.8 yrs	Whole body vibration training/standing	2 x w 3 x 2 min 28 Hz 0.1-10 g lateral oscillation	6 m	↔
Verschueren et al. (2004)	n=25 f 61.3-67.9 yrs	Static and dynamic strength exercises on vibration platform	3 x w 35-40 Hz A 1.7-2.5 mm	6 m	↑
Iwamoto et al. (2005)	n=25 f 55-58 yrs	Whole body vibration training	1 x w 4 min 20 Hz A 0.7-4.2 mm	12 m	↑ similar increase in both groups (E & C)
Gusi et al. (2006)	n=14 f 66 yrs	Whole body vibration training	3 x w 6 x 1 min 12.6 Hz	32 w	↑
Ruan et al. (2008)	n=51 f 53-69.4 yrs	Whole body vibration training	5 x w 10 min 30 Hz A 5 mm	6 m	↑ (after 3 and 6 months)
Fjelstad et al. (2009)	n=21 f 61.7-63.9 yrs	Whole body vibration training + strength exercises with loading	3 x w 15-30 do 40 Hz	8 m	↓
Humphries et al. (2009)	n=51 f (21.02 yrs)	a) Whole body vibration training b) Whole body vibration training + training with loading c) Control		16 w	↑ a and b
Bemben et al. (2010)	n=55 f postmenopausal women with estrogen deficiency	a) Training with loading b) Whole body vibration training + training with loading for upper and lower body c) Control	3xw 80%1RM 20-40 Hz, 2-2.8 g	8 m	↔ (↓ BMD compared to Con in right hip)
Ruck et al. (2010)	n=6 f 6.2-12.3 yrs Pilot study	Whole body vibration training	5 x a week for 9 min	6 m	↔
Von Stengel et al. (2011)	n=63 f (a29+b34) postmenopausal 64-72 yrs	Unilateral and bilateral squat during: a) Rotation vibration training (12.5Hz, 12 mm, 15 min) b) Vertical vibration training (35Hz,1.7mm, 15min) + vitamin D	3 x w 7 x 90 s a) 12.5 Hz, 12 mm, 15 min b) 35 Hz, 1.7mm, 15 min	12 m	↑ a and b (a -significantly, b - vertical bordering on significant)

Von Stengel et al. (2011)	n=108 f postmenopausal 65.4-71.6 yrs	Whole body vibration training + combined dance aerobics, balance, functional gymnastics and dynamic leg strength + vitamin D	2 x w + 2 x w at home 25-35 Hz A 1.7 mm Combined: 70-80 HR_{max}	18 m	↑
Verschueren et al. (2011)	n=54 f postmenopausal >70 yrs	Static and dynamic exercises on vibration platform + vitamin D	3 x w 1-12 min 30-40 Hz A 1.6-2.2 g	6 m	↑ increase in experimental and control group with no differences
Prioreschi et al. (2012)	n=15 trained cyclists (8+7)	a) Whole body vibration training (30Hz) + normal bicycle training b) Con – normal bicycle training	3 x w 30 Hz	10 w	↑ a

*n - number of participants in experimental group or in more of them; ↑ statistically significant increase; ↔ no statistically significant change; ↓ statistically significant decrease; m - male; f - female.

The effects of participation in sport games on bone mass

It is interesting that there are not many studies dealing with the effects of sports games on bone mass in untrained population considering the great value of sports games (football, handball, basketball, volleyball, tennis) in terms of their benefits on psycho-social and physical health.

A good example of one of those studies is the one carried by Danish scientists (Krustrup, et al., 2010; Helge, et al., 2010; Randers, et al., 2010), in which they tested the effects of the most popular sport – football, on fitness health, or indicators of musculoskeletal and cardiovascular health (Table 6).

The importance of frequency of training, or total loading for achieving optimal effects on bone mass, was made known by Randers et al. (2010) in their study wherein untrained men underwent 2.4 training sessions per week over a period of 12 weeks and later reduced the frequency of training to 1.3 sessions per week. Specifically, leg bone mass and density were significantly enhanced after first 12 weeks of training; however, after reducing the number of sessions over the following 52 weeks no changes were recorded. Therefore, when programming training whose purpose is to enhance bone quality, it is an imperative to take frequency into account, that is, total loading which is higher than everyday loading, or loading that will activate stimulus threshold crucial for initiating osteogenic effects in the organism. Also, if we want to maintain current bone mass and density and at the same time achieve other objectives using different types of training, we can reduce the number of football training sessions and as a result realize various goals of our training process, that is develop quality, multilateral training program.

However, positive osteogenic stimulus of sports games is evident from scientific studies (chapter 3) which have reported more bone mass quality in athletes involved in such sports compared to athletes involved in other sports. Their positive osteogenic stimulus is also evident in previously mentioned characteristics such as high impact and random loads. Therefore, sports games should definitely be considered as a potential means of bone mass accrual, particularly in young population.

Table 6. The effects of sport games on bone mass

Study	Participants (number, gender and age)	Modality of training/ exercise	Loading (training intensity and volume)	Duration of the program (months/m or weeks/w)	Program effects
Randers et al. (2010)	17 untrained men 7 control (22.9±1.8 yrs)	High-intensity recreational football training	2.4 x w over 12 w 1.3 x w over 52 w	total 64 weeks	Increase in leg bone mass and density After 12 w (identical to that after 64) legs

Helge et al. (2010)	50 (25 + 25) untrained women (36.5±7.7 yrs)	Football training Endurance training (unbroken running)	1.8 x w football 1.9 x w endurance	14 w	BMD increased in both groups Football group significantly higher tibia
Krustrup et al. (2010)	19 (9+10) untrained women 9 con (19-47 yrs)	Football training Endurance training (incessant running)	~2 x 1 hour w	16 m	Whole body BMD significantly increased in the football group vs. the endurance group

Conclusions

The importance of physical activity in enhancing bone quality, i.e. increasing bone mass and strength, has been evidenced by a number of studies showing positive effects of sport and various types of training on human multiple properties. This is supported by study findings which indicate that physical training is potentially superior to the supplementation with essential minerals in metabolism and bone mass formation (Hemayattalab, 2010; Arab Ameri, et al., 2012).

As regards type of training, or type of physical activity with the highest potential for increasing bone mass, there are two activities that stand out – performance against great loadings and jump exercises, that is, strength training and plyometric training.

Another type of training aiming at increasing bone mass that has lately come into focus is vibration training. Compared to the former two, which are more appropriate for young population, it is more appropriate for elderly population due to its simplicity and safety.

Apart from vibration training, aerobic training significantly affects cardiovascular health and shows certain indications of improving or at least maintaining bone mass.

Therefore, if we want to maintain optimal bone mass throughout life, it is recommendable to participate in systematic sports training from early childhood on a regular basis over longer periods of time and to regularly involve oneself in physical activities, especially those creating greater ground reaction forces and those with external loadings larger than those of everyday life.

It is a challenging task to come to a valid conclusion about optimal loading parameters for specific types of training due to the inconsistency in methodological approaches and, often, controversial findings. Hence, future research should focus on: a) the determination of optimal loading parameters for specific types of training and age groups with a uniform methodology; b) topological effects of specific exercises, especially in strength and jump training programs; c) the determination of effects of agility training as a potential protocol for developing bone mass in young population; and d) the determination of residual effects of training programs focused on gaining bone mass, that is, the effects of detraining.

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Correspondence to:
Cvita Gregov, Ph.D.
Faculty of Kinesiology, University of Zagreb
Horvaćanski zavoj 15
10 000 Zagreb, Croatia
Phone: +385 1 3658 602
E-mail: cvita.gregov@kif.hr

UČINCI RAZLIČITIH MODALITETA TRENINGA NA KOŠTANU MASU: PREGLED ISTRAŽIVANJA

U današnje vrijeme brojna se istraživanja bave problemom osteoporoze zbog eksponencijalnog rasta broja prijeloma u starijoj populaciji. Rizik od fraktura usko je povezan s prirodnim gubitkom koštane mase u žena i muškaraca koji nastaje kao posljedica starenja. Zbog očitih demografskih promjena, odnosno cjelokupnog porasta starenja stanovništva, broj prijeloma je viši od očekivanog, što ukazuje na to da se kvaliteta kostiju pogoršava iz jedne generacije u drugu. Da bi se spriječilo propadanje kostiju, potrebno je pronaći odgovarajuće profilaktičke i terapijske postupke. Osim standardnih metoda suplementacije kalcijem i vitaminom D, a čiji učinak na očuvanje koštane mase nije velik, jedna od najboljih ne-farmakoloških metoda za cjeloživotno poboljšanje koštane mase jest tjelovježba, odnosno sudjelovanje u kvalitetno osmišljenom treningu, o čemu svjedoče i brojna istraživanja. Međutim, iskustvo i znanstvena istraživanja upućuju na to da nisu svi modaliteti vježbanja jednako učinkoviti u povećanju koštane mase, odnosno postoje modaliteti koji mogu znatno utjecati na kvalitetu kostiju, a ima i onih koji na nju neće znatnije utjecati. Dakle, pregledom dosadašnjih istraživanja željelo se otkriti koji su modaliteti tjelovježbe najučinkovitiji za poboljšanje kvalitete koštane mase u različitim dobnim skupinama. O važnosti tjelesne aktivnosti za poboljšanje kvalitete kostiju, odnosno povećanje koštane mase i jakosti svjedoče brojni istraživački radovi koji pokazuju pozitivne učinke sporta i raznih vrsta treninga na navedena svojstva. Tome u prilog idu i rezultati istraživanja koji ukazuju na to da je trening potencijalno bolja metoda od suplementacije esencijalnim mineralima za metabolizam kostiju i održanje koštanu masu. Što se vrste treninga tiče ili vrste fizičke aktivnosti s najvećim potencijalom za povećanje koštane mase, postoje dva tipa aktivnosti koje se ističu: izvođenje vježbi velikim opterećenjem i vježbe skokova, odnosno vježbe jakosti i pliometrijski trening. Treći tip treninga usmjeren na povećanje koštane mase, koji se ističe u zadnje vrijeme, jest vibracijski trening, ali u odnosu na prethodna dva tipa treninga, koji su prikladniji za mlađu populaciju, vibracijski je trening zbog svoje jednostavnosti i sigurnosti puno prikladniji za stariju populacije. Aerobni trening znatno utječe na zdravlje kardiovaskularnoga sustava te pokazuje određene indikacije za poboljšanje ili barem održavanje koštane mase. Stoga, želi li se zadržati optimalna koštana masa tijekom života, preporuča se sudjelovanje u sustavnom sportskom treningu od ranog djetinjstva i redovito bavljenje tjelesnim aktivnostima, osobito onima koje karakteriziraju veće sile reakcije podloge te primjena vanjskih opterećenja većih od onih u svakodnevnim aktivnostima, i to tijekom dužeg razdoblja. Zbog nedosljednosti u metodološkim pristupima i često kontroverznim rezultatima dosadašnjih istraživanja, pronalaženje kvalitetnih spoznaja o optimalnim parametrima pojedinih vrsta treninga s ciljem unapređenja koštane mase predstavlja velik izazov. Stoga bi se buduća istraživanja trebala usmjeriti na: a) određivanje optimalnih parametara za određene vrste treninga i dobne skupine jedinstvenim metodološkim pristupom; b) utvrđivanje topoloških učinaka određenih vježbi, pogotovo vježbi jakosti i skokova; c) utvrđivanje učinaka treninga agilnosti kao potencijalnog protokola za razvoj koštane mase mlađih dobnih skupina i d) određivanje rezidualnih učinaka treninga na koštanu masu, tj. utvrđivanje učinaka detreniranosti.

Ključne riječi: *mineralna gustoća kostiju, osteoporoza, vježbanje, jakost, pliometrija*