TITLE

A short-term adapted physical activity program improves bone quality in osteopenic/osteoporotic postmenopausal women evaluated by phalangeal osteosonography

RUNNING HEAD:

Exercise and bone quality in postmenopausal women

KEY WORDS:

Exercise program - bone health - phalangeal osteosonography

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ABSTRACT

Background and aims: It is known that people affected by osteopenia/osteoporosis can benefit from an adequate amount of physical activity, counteracting the progressive loss of bone and muscle mass due to aging. Moreover, there is increasing evidence that exercise has positive effects on bone structure.

The aim of our study was to evaluate the effects on bone tissue and muscular strength of a short-term exercise program in osteopenic/osteoporotic postmenopausal women. **Methods:** 49 osteopenic/osteoporotic postmenopausal women were divided in 2 groups, exercise and control. All subjects underwent two evaluations, before and after a training period. Bone quality was assessed by phalangeal quantitative osteosonography, and maximal strength of leg extensor muscles was also evaluated. The experimental group participated in a specific supervised 20-week physical activity program, including aerobic, balance and strength training. **Results:** After the training period all bone parameters and lower limb maximal strength were significantly improved in the exercise group ($p<0.05$), while no significant changes were observed in the control group. **Conclusions:** Our study shows that a broad-based training protocol, lasting 20 weeks, may improve leg strength and bone quality parameters, main determinants of fall and fracture risk, respectively.

INTRODUCTION

Regular physical activity has been demonstrated to play an essential role in maintaining or improving density and mechanical strength of bones (1-3).

The majority of researches suggest that short bouts of high resistance exercises induce the greater benefits on BMD although this effect seems to be mainly site specific (4-6); however the optimal duration, intensity, frequency and protocol of physical activity able to increase bone mineral density (BMD) have been not yet determined. Further, BMD can only partially explain the effect of exercise on skeletal bones, in fact exercise seems to influence also bone micro-architecture, elasticity and resistance. It is known that Dual X-ray absorptiometry provides only a quantitative measurement of bone, while ultrasound methods can measure something different from bone mineral content and density that is generally defined as bone quality (7-10). Only a few studies employed this method to assess the effect of exercise on bone tissue.

The aim of this study was to evaluate if a supervised short-term adapted exercise program (20 weeks) can induce detectable improvements on bone ultrasound parameters of osteopenic/osteoporotic postmenopausal women.

MATERIALS AND METHODS

Subjects' recruitment

110 postmenopausal women who were daughters of osteoporotic fractured women were contacted and were offered to undergo an osteoporosis phalangeal osteosonography screening with preventive purpose. 84 women who shown a t-score < -1.0 SD were asked to take part in the study. 64 of theme accepted and gave their informed consent to participate. By a simple

randomization they were then divided into 2 groups, experimental (E) and control (C): 36 women were assigned to the experimental group and 28 to the control group.

The larger size of the experimental group was chosen to prevent a loss of statistical power due to subjects drop out.

Criteria of inclusion were the following:

1. postmenopausal women (age between 50 and 70);
2. diagnosis of osteopenia or osteoporosis (t-score determined by ultrasounds < -1.0 SD);
3. lack of any diseases that affects bone metabolism;
4. no previous skeletal fractures;
5. lack of any contraindication to perform physical activity.

During the training period (20 weeks) we registered a drop-out of 7 subjects in the experimental group, owing to health or personal problems, and 8 subjects of the control group did not accept to repeat the tests at the end of the study. No significant differences were observed between the subjects who dropped out and the subjects who remained in the study.

Anthropometric characteristics of subjects are presented in Table 1.

Drug therapy was not the same for all the subjects and some of them were not taking any drug. However, no significant differences were present between groups.

Table 2 shows the drug assumption within each group.

The experimental group followed a specific supervised activity program including balance, aerobic and strength training (3 times/week for 20 weeks). The lessons were conducted by a certificated instructor, specialized in adapted physical activity and took place both in a clinical setting (hospital rehabilitation unit) and in a gym. All subjects were instructed to maintain their physical activity habits, drug therapy and usual diet until completion of the study.

Evaluation before and after the training period

All subjects underwent two different evaluations:

1. Bone quality assessment, by phalangeal quantitative osteosonography (DBM Sonic 1200, IGEA S.r.l., Carpi (MO), Italy) performed at the fingers of the non-dominant hand. The DBM Sonic 1200 measures the amplitude-dependent speed of sound through the bone (Ad-Sos, expressed in m/s), and the ultrasound bone profile score (UBPS), which is an index calculated from the ultrasound graphic trace, giving a quantitative evaluation of the ultrasound signal characteristics. Both these parameters are related to bone density and elasticity (11).

All the evaluations were carried out always by the same experienced operator in a single-blind design. The short-term precision of the instrument was determined on a series of repeated measurements performed on two subjects, in terms of coefficient of variation (CV%) for Ad-Sos measures. The coefficient we obtained (0.61%) was similar to other previous studies (12-13). Subjects who participated in the study were daughters of fractured osteoporotic women and were evaluated for preventive purpose. Since osteosonography is a good, fast, non-invasive and not expensive screening tool we decided to administer only this kind of evaluation. Subjects who shown poor bone qualities (e.g. low t-score) were then advised to take also a conventional bone assessment (e.g. dual x-ray absorbimetry).

2. Maximal strength production of knee extensor muscles (1-RM) was estimated by an isotonic leg-extension machine (Leg-extension R.O.M., with power control system, Technogym S.p.A., Gambettola (FC), Italy). The 1-RM was calculated from the 10-RM max using a prediction

equation [1-RM = 1.554 x (10-RM weight) – 5.181] (14). 10-RM was taken as the heaviest weight that each subject was able to lift 10 times throughout a complete range of motion. The 10-RM was achieved by increasing the load by 5 kg after each successful set of lifts (10 lifts per set), until the maximum load sustainable for 10 lifts was obtained. Subjects had a five minute rest interval between each weight increment.

Training protocol

The program consisted of 60 supervised exercise-sessions (3 times a week over a period of 20 weeks) including:

- two 60-minute sessions consisting of callisthenic/isometric exercises, and exercises with dumbbell, thera-band and balls, aimed to improve joints range of motion, overall strength, balance and aerobic capacity;
- one 45-minute session consisting of a combination of aerobic endurance and strength exercises (using different ergometers and weight machines).

Each 60-minute exercise session included a warm-up phase lasting about 20-25 minutes (walking, stretching, small jumps), followed by a 30-minute training-phase (with exercises for large and small muscle groups). During the last 5-10 minutes, subjects were instructed to cool-down, with stretching, breathing and postural exercises.

The progression of the exercise volume was obtained by a graded increase of the exercise intensity, number of repetitions and series, starting after the fifth week of training.

Each 45-minute exercise session included a circuit-training, consisting in 6 bouts of exercise lasting 5 minutes each: I) treadmill; II) leg-extension; III) arm-ergometer; IV) horizontal leg-press; V) bike; VI) lat-machine.

Aerobic training (I, III, V) consisted of low intensity exercises, during the first period performed at a preset intensity (speed of 3.5 km/h for treadmill, power of 60 watt for arm-ergometer and power of 80 watt for bike), then adapted to the individual level of capacity and rate of perceived exertion (RPE Borg Scale) (15). Subjects were instructed to perform the exercises between 10-13 levels (accordingly to the 6-20 RPE Scale).

With respect to strength exercises (II, IV, VI), throughout the training period, subjects were instructed to increase the number of repetitions, or the load lifted, with the aim to get progressively a higher amount of exercise volume during each 5-minute strength exercise bout, but without exceed the RPE intensity of 10–13 (6-20 RPE Scale).

Since it is known that exercise has a site-specific bone mineral content increasing effect (16, 17), all the strength exercises were selected in order to not directly load the phalanges. However, handling dumbbell, thera-band and balls could have induced a non-planned load.

Statistical analysis

The baseline characteristic of the experimental and control groups were compared by Student's *t*-test. Two-tailed analysis of variance was used to compare the differences among the groups in the changes in bone and muscle strength measurement data and to assess the efficacy of the training period on the experimental group respect to the control group; the paired *t*-test was used to analyze the longitudinal changes within the groups. The alpha value was set at $p<0.05$.

Statistical analysis has been performed using the Statistical Package for Social Sciences, SPSS version 11.0 for Windows. The results are expressed as the mean value ±SD.

RESULTS

Basal values and drug therapy assumption did not show any significant difference among groups (Tables 1 and 2).

As shown in Table 3, after the training period, in E we observed an improvement of all measured parameters in comparison to baseline values and to C.

Amplitude-dependent speed of sound (Ad-Sos), the most important parameter to evaluate bone quality, significantly increased after the training period only in the experimental group (from 1956.2±80.0 to 1977.8±74.4 m/s; $p<0.05$).

The ultrasound bone profile score (UBPS) improved in all groups, but significantly only in the experimental group, increasing from 31.7±18.6 to 36.8±21.3 in E ($p<0.05$) and from 33.6±16.8 to 36.5±17.2 in C.

In E, t-scores significantly improved (from -2.4±1.1 to -2.1±1.1; $p<0.05$), while C group didn't show any significant change.

Finally, after the training period, the maximal strength of knee extensor muscles significantly improved in E (from 44.1±11.0 to 52.7±9.5 kg; $p<0.05$), whereas no significant changes were observed in C.

DISCUSSION

This study shows that a planned training period of supervised adapted physical activity (lasting 20 weeks), significantly improves bone quality (assessed at hand phalanges) and leg strength in osteopenic/osteoporotic postmenopausal women.

Our physical activity protocol consisted mainly of aerobic and resistance training, but included also joint mobility, coordination and balance exercises. Several papers demonstrated that these exercise modalities are useful to maintain/improve bone mass and fundamental in preventing falls (18-22).

Several studies (18, 24; see 1 for a review) considered the efficacy of physical activity in osteoporotic patients, but, at present, only few studies evaluated the effects of a training period on bone quality (25, 26).

The purpose of our study was to evaluate the effects of a supervised short-term adapted physical activity program on bone tissue quality, in postmenopausal women with osteopenia/osteoporosis.

We investigated bone quality by phalangeal osteosonography, whose parameters appear significantly correlated both with bone mineral density (BMD), and with qualitative properties of bones, such as micro-architecture, resistance, elasticity. All these parameters have been demonstrated to be predictors of fracture risk independently of BMD (27-30).

To date, only Vainionpaa A. (2005) and Ay A. (2005) using the calcaneal broadband ultrasound attenuation (BUA), evaluated the effects of a training period on bone quality, in postmenopausal women, showing a significant improvement in the exercise group compared to a control group (25, 26).

Despite a shorter duration of our protocol in comparison with other studies (18, 22, 24-26) we obtained a significant increase of all bone parameters (Ad-Sos, UBPS and t-score) in the exercise group. These early positive effects of our training on these parameters may be interpreted more as a qualitative adaptation of bone structure than a quantitative improvement of BMD that generally occurs after a more prolonged period of training (18, 22). Furthermore, since the osteosonography was performed on the proximal phalanges of the hand, our results could be interpreted as a site-specific mechanical stimulus of strength exercises, involving the hands. This represents also an important limitation of our study since many papers have already shown that exercise has site-specific effect on bone (16, 17).

However owing to the multi-dimensional (involving whole-body) exercise protocol, the positive effect showed on bone finger's quality, could be observed also at different bone sites.

Finally, isometric leg strength has been demonstrated as important predictor to determine the risk of falls in elderly (31, 32). The improvement we observed on strength evaluation demonstrated the effectiveness of our training protocol: maximal leg strength significantly increased in exercise group, while showed a slight but not significant reduction in control group. Considering that a progressive loss of strength affects all aging populations, these data confirm the importance of a specific training protocol in postmenopausal women with a low BMD, able not only to improve bone quality, but also to reduce the risk of falls.

CONCLUSIONS

In conclusion we can state that in a group of postmenopausal women a supervised multi-dimensional exercise program improves bone quality, evaluated at the finger, in a relatively short period of time.

Also, the study confirms that people affected by osteopenia/osteoporosis can benefit from an adequate amount of physical activity to counteract the progressive loss of bone and muscle mass due to aging.

REFERENCES

1. Todd JA, Robinson RJ. Osteoporosis and exercise. *Postgrad Med* J 2003;79:320-3.
2. Wallace BA, Cumming RG. Systematic review of randomized trials of the effect of exercise on bone mass in pre- and postmenopausal women. *Calcif Tissue Int* 2000;67:10-8.

3. Martyn-StJames M, Carroll S. High-intensity resistance training and postmenopausal bone loss: a meta-analysis. *Osteoporos Int* 2006;17:1225-1240.

4. Kelley GA. Exercise and regional bone mineral density in postmenopausal women: a meta-analytic review of randomized trials. *AM J Phys Med Rehabil* 1998;77:76-87.

5. Kelley GA, Kelley KS, Tran ZV. Exercise and bone mineral density in men: a meta-analysis. *Prev Med* 1998;27:798-807.

6. Kerr D, Morton A, Dick I, Prince R. Exercise effects on bone mass in postmenopausal women are site-specific and load-dependent. *J Bone Miner Res* 1996;11:218-25.

7. Kaufman JJ, Einhorn TA. Ultrasound assessment of bone. *J Bone Miner Res* 1993;8:517-25.

8. Njeh CF, Boivin CM, Langton CM. The role of ultrasound in the assessment of osteoporosis: a review. *Osteoporos Int* 1997;7:7-22.

9. Genant HK, Engelke K, Fuerst T, et al. Noninvasive assessment of bone mineral and structure: state of the art. *J Bone Miner Res* 1996;11:707-30.

10. Gregg EW, Kriska AM, Salamone LM, et al. The epidemiology of quantitative ultrasound: a review of the relationships with bone mass, osteoporosis and fracture risk. *Osteoporos Int* 1997;7:89-99.

11. Di Stefano M, Carlo Isaia G. Ability of ultrasound bone profile score (UBPS) to discriminate between fractured and not fractured osteoporotic women. *Ultrasound Med Biol* 2002;28:1485-9.

12. Gnudi S, Ripamonti C. Quantitative ultrasound at the phalanxes discriminates osteoporotic women with vertebral but not with hip fracture. *Ultrasound Med Biol* 2004 Mar;30:357-61.

13. Camozzi V, De Terlizzi F, Zangari M, Luisetto G. Quantitative bone ultrasound at phalanges and calcaneus in osteoporotic postmenopausal women: influence of age and measurement site. *Ultrasound Med Biol* 2007;33:1039-45.

14. Braith RW, Graves JE, Leggett SH, Pollock ML. Effect of training on the relationship between maximal and submaximal strength. *Med Sci Sports Exerc* 1993;25:132-8.

15. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* 1970;2:92–8.

16. Beverly MC, Rider TA, Evans MJ, Smith R. Local bone mineral response to brief exercise that stresses the skeleton. *BMJ* 1989;299:233-5.

17. Adami S, Gatti D, Braga V, Bianchini D, Rossini M. Site-specific effects of strength training on bone structure and geometry of ultradistal radius in postmenopausal women. *J Bone Miner Res.* 1999;14:120-4.

18. Kemmler W, Engelke K, Weineck J, Hensen J, Kalender WA. The Erlangen Fitness Osteoporosis Prevention Study: a controlled exercise trial in early postmenopausal women with low bone density-first-year results. *Arch Phys Med Rehabil* 2003;84:673-82.

19. Robertson MC, Campbell AJ, Gardner MM, Devlin N. Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. *J Am Geriatr Soc* 2002;50:905-11.

20. Morgan RO, Virnig BA, Duque M, Abdel-Moty E, Devito CA. Low-intensity exercise and reduction of the risk for falls among at-risk elders. *J Gerontol A Biol Sci Med Sci* 2004;59:1062-7.

21. Liu-Ambrose T, Khan KM, Eng JJ, Janssen PA, Lord SR, McKay HA. Resistance and agility training reduce fall risk in women aged 75 to 85 with low bone mass: a 6-Month randomized, controlled trial. *JAGS* 2004;52:657-65.

22. Englund U, Littbrand H, Sondell A, Pettersson U, Bucht G. A 1-year combined weight-bearing training program is beneficial for bone mineral density and neuromuscular function in older women. *Osteoporos Int* 2005;16:1117-23.

23. Yamazaki S, Ichimura S, Iwamoto J, Takeda T, Toyama Y. Effect of walking exercise on bone metabolism in postmenopausal women with osteopenia/osteoporosis. *J Bone Miner Metab* 2004;22:500-8.

24. Chien MY, Wu YT, Hsu AT, Yang RS, Lai JS. Efficacy of a 24-Week Aerobic Exercise Program for Osteopenia Postmenopausal Women. *Calcif Tissue Int* 2000;67:443-8.

25. Vainionpaa A, Korpelainen R, Leppaluoto J, Jamsa T. Effects of high-impact exercise on bone mineral density: a randomized controlled trial in premenopausal women. *Osteoporos Int* 2005;16:191-7.

26. Ay A, Yurtkuran M. Influence of aquatic and weight-bearing exercises on quantitative ultrasound variables in postmenopausal women. Am J Phys Med Rehabil. 2005;84:52-61.

27. Mele R, Masci G, Ventura V, Bicicchi M, Cadossi R. Three year longitudinal study with quantitative ultrasound at the hand phalanx in a female population. *Osteoporos Int* 1997;7:550-7.

28. Hartl F, Tyndall A, Kraenzlin M, et al. Discriminatory ability of quantitative ultrasound parameters and bone mineral density in a population-based sample of

postmenopausal women with vertebral fractures: results of the Basel Osteoporosis Study. *Bone Miner Res* 2002;17:321-30.

29. Bauer DC, Gluer CC, Cauley JA, et al. Broadband ultrasound attenuation predicts fractures strongly and independently of densitometry in older women. A prospective study. Study of Osteoporotic Fractures Research Group. *Arch Intern Med* 1997;157:629-34.
30. Alexandersen P, De Terlizzi F, Tankò LB, Bagger YZ, Christiansen C. Comparison of quantitative ultrasound of the phalanges with conventional bone densitometry in healthy postmenopausal women. *Osteoporos Int* 2005;16:1071-78.
31. Takazawa K, Arisawa K, Honda S, Shibata Y, Saito H. Lower-extremity muscle forces measured by a hand-held dynamometer and the risk of falls among day-care users in Japan: using multinomial logistic regression analysis. *Disabil Rehabil* 2003;25:399-404.
32. Rubenstein LZ, Josephson KR, Trueblood PR, et al. Effects of a group exercise program on strength, mobility, and falls among fall-prone elderly men. *J Gerontol A Biol Sci Med Sci* 2000;55:M 317-21.

TABLES

Table 1. GENERAL AND ANTHROPOMETRIC CHARACTERISTICS OF SUBJECTS [a]

	E[b]	C[b]
Number of subjects	29	20
Age (yrs)	59.4±4.3	57.7±4.7
Age at menopause (yrs)	48.2±5.8	49.2±3.6
Weight (kg)	70.0±9.8	69.8±10.3
Height (cm)	160.0±4.3	161.1±5.3

[a] Data are expressed as mean ± SD

[b] E = Experimental group; C= Control group

Table 2. DRUG ASSUMPTION WITHIN GROUPS

	Ca – D3	Bisphosphonates	Raloxifen	HRT	No therapy
Experimental (n.29)	6 [a] (20.7%) [b]	8 (27.6%)	1 (3.4%)	2 (6.9%)	12 (41.4%)
Control (n.20)	4 (20.0%)	5 (25.0%)	1 (5.0%)	1 (5.0%)	9 (45.0%)

[a] Number of subjects

[b] Percentage

Table 3. RESULTS BEFORE (1) AND AFTER (2) THE 20-WEEK TRAINING PERIOD [a]

	Ad-Sos[c]		UBPS[d]		t-score		Leg-Extension[e]	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**
E[b]	1956.2±80.0	1977.8±74.4*	31.7±18.6	36.8±21.3*	-2.4±1.1	-2.1±1.1*	44.1±11.0	52.7±9.5*
C[b]	1962.6±84.3	1968.9±74.6	33.6±16.8	36.5±17.2	-2.3±1.2	-2.3±1.2	41.4±8.0	37.9±6.8*

[a] Data are expressed as mean ± SD; * $p<0.05$

[b] E = Experimental group; C= Control group

[c] Amplitude-dependent Speed of sound

[d] Ultrasound Bone Profile Score

[e] Maximal Leg extension strength