The role of exercise and diet in maintaining bone health

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Abstract Prevention is the most important measure against osteoporosis, since bone mass, once it is lost, cannot be recovered. Bone mass, in both men and women, reaches a maximum level in the 20s to 30s age range, and maintains this level or slightly increases toward the 40s, and gradually decreases thereafter. In particular, bone mass dramatically decreases in postmenopausal women because of a decrease in serum estrogen level. Bone mass is influenced by genetic and environmental factors such as mechanical loading, nutrition, and lifestyle, besides gender, age, and metabolic factors. Among these factors, mechanical loading, i.e. exercise, and nutrition seem to be important in maintaining bone health, since they are expected to improve with changes in lifestyle. Routine exercise and a diet rich in minerals and vitamins, throughout life, both contribute to maintaining bone health.

Keywords : exercise, nutrition, diet, postmenopausal women, bone health, osteoporosis

Introduction

Prevention of osteoporosis is a key health issue in Japan, because the number of people with osteoporosis is estimated to be approximately 12 million. Bone mass, in both men and women, reaches a maximum level in the 20s to 30s age range, and maintains this level or slightly increases toward the 40s, and gradually decreases thereafter (Fig. 1). In particular, bone mass dramatically decreases in postmenopausal women and, as a result, women with osteoporosis outnumber men with the condition by a ratio of 3 to 1. The main cause of osteoporosis is thought to be estrogen deficiency; however, routine exercise and a diet rich in minerals and vitamins are both important in preventing osteoporosis. In this review, the scientific evidence focusing on osteoporosis prevention in postmenopausal women will be discussed.

Osteoporosis

The NIH Consensus Conference adopted the definition of osteoporosis as a skeletal disorder that is characterized by compromised bone strength leading to a predisposition for and an increased risk of fracture¹⁾. On the basis of this definition, Yoshimura et al. estimated that the prevalence of osteoporosis in Japan will reach 12.8 million²⁾. The prevalence rate increases with age, and particularly in women, this rate was higher than that in men because of estrogen deficiencies later in life³⁾.

In skeletal tissues, bone formation and resorption both play a role in bone remodeling. In the postmenopausal bone tissue, high bone turnover is observed because the bone resorption rate is higher than the bone formation rate, thereby causing a decrease in bone mass. This phenomenon is attributable to estrogen deficiency, which protects osteoclast activity involving bone resorption.

Effect of exercise on bone mass

It has been reported that bone loss occurs in patients under long-term bed rest and in astronauts in a zero-gravity environment. Therefore, mechanical stress is an important factor in maintaining healthy bone mass. Additionally, many cohort studies and meta-analyses have shown that

Fig. 1 Relationship between aging and bone mass

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the risk of bone fractures decreases as the amount of physical activity increases⁴). This effect is probably age-dependent. However, appropriate physical activity during the growing stages is very important for osteoporosis prevention because this results in a higher peak bone mass. In addition, it has been reported that mechanical stress acts to oppose bone loss in postmenopausal women⁵). This evidence shows that mechanical stress is an important factor in maintaining adequate bone mass. Table 1 summarizes the results from interventional studies focusing on the effect of exercise on postmenopausal women. Seven of the 8 trials reported demonstrated a positive effect of regular exercise on bone mass in postmenopausal women⁶).

Recker et al. reported that bone turnover was 2 and 3 times faster at 1 and 13 years, respectively, after menopause than in the pre-menopausal state⁷). For this reason, it has been speculated that the effectiveness of exercise on bone mass in menopausal women may depend on the bone turnover rate. Only moderate exercise is recommended in middle-aged and elderly people because it is still beneficial for bone mass and carries a lower risk of injury than higher-intensity activities. Low-intensity exercises, such as walking, are appropriate and effective in older populations. Swimming is also a good choice of exercise, and has recently been shown to provide benefits to bone mass in women⁵). Conversely, it has been reported that excessive exercise may lower estrogen levels, which, in turn, can lead to low mineral densities in young female athletes⁸). Because stopping exercise also terminates its benefits on bone mass, it is desirable to continue regular

exercise routines for as long as possible.

Effects of nutrition on bone mass

Skeletal tissue consists of bone matrix protein (e.g., collagen) and minerals (e.g., calcium and phosphorus). Therefore, it is obvious that calcium is an important nutrient for the prevention of osteoporosis. Calcium accounts for 1 to 2% of the total body weight, and more than 99% of the body calcium is found in the skeletal tissue and in the teeth. The recommended daily allowance (RDA) of calcium, based on the estimated average requirement in the Dietary Reference Intakes (DRIs) for Japanese (2010), is 800 mg/day for adult men and 650 mg/day for adult women (Table 2)⁹). Although some reports have shown no relationship between calcium intake and bone mineral density in postmenopausal women¹⁰), it is widely accepted that sufficient calcium intake throughout life leads to better bone health and prevents osteoporosis.

Vitamin D stimulates calcium absorption in the intestine and induces calcium re-absorption in the distal tubules of the kidneys. It has also been reported that a combination of calcium and vitamin D supplementation increases bone mineral density in postmenopausal women^{11,12}). Vitamin K also plays an important role in bone formation. It stimulates γ -carboxylation of osteocalcin, which leads to enhanced bone mineralization. Thus, adequate vitamin and mineral intake should be considered for the preservation of bone health. The recommended intake values of nutrients related to bone metabolism, as reported by the Japan Osteoporosis Society, are shown in Table 3⁶). Protein also

Table 1. Intervention studies of exercise on bone mineral density in postmenopausal women

Exercise	Strength	Number of times	Frequency	Term	Result	Evidence level*
Heel up (at home)		50 times	Every day + 1/wk	1y	○	II
Weight bearing exercise (Walking etc.), Aerobics, Stretching		60 min	3 times /wk	1y	△	IV
Resistance training	RM	8 × 3 set or 20 × 3 set		1y	△	II
Hip flexion	5kg	60 times		2y	○	III
Aerobics and Step exercise			2 times /wk	1.5y, 8 month personal	○	II
Resistance training on muscle of the back	30% of 1RM	10 × 3 set	5 times /wk	2y	After 10y ○	II
Jump aerobics and Step exercise		45 min	3 times /wk	1y	×	II
Tai Chi		45 min	5 times /wk	1y	○	II

RM: repetition maximum, ○: effective, △: partially effective, ×: not effective (arranged ref. 6)

*Evidence level: I; Meta analysis/Systematic review, II; more than one of RCT, III; other than RCT, IV; observational study.

plays an important role in preserving bone quality. Excessive intake of sodium, phosphorus, caffeine, alcohol, and smoking are detrimental to bone health and should be avoided.

Effects of functional food components on bone health

Soybean isoflavones have chemical structures similar to that of estrogen, and have a weak affinity for estrogen receptors. This suggests that isoflavones may exhibit estrogenic actions in various tissues (Fig. 2)¹³⁾, and they have received considerable attention because of their potential to prevent bone loss in postmenopausal women, as well as osteoporotic animal models^{14,15)}. Although there have been several randomized controlled trials that demonstrate no relationship between isoflavone intake and bone mass, recent meta-analyses have shown beneficial effects of isoflavone on postmenopausal bone metabolism¹⁶⁾. The Consumer Affairs Agency of the Japanese government has declared isoflavones as a principle ingredient on the list

of Foods for Specified Health Uses (FOSHU). Milk basic proteins (MBP) are also on the FOSHU list because they increase bone mineral density by stimulating bone formation, while suppressing bone resorption¹⁷⁾.

Cooperative effects of exercise and food components

There is a shortage in the intake of calcium in Japanese individuals, especially among adult men and women. Elderly people, in particular, require more vitamins that play an important role in bone metabolism, such as vitamin D and K. Since the incidence of osteoporosis is increasing each year, and fractures are the third-highest cause for becoming bedridden, the maintenance of healthy bones is an important factor in extending a person's healthy lifespan. Therefore, we examined the cooperative effects of exercise and soy isoflavones, which have shown weak estrogenic effects on bone metabolism in postmenopausal Japanese women.

We assigned 136 subjects (average age, 55 years), who had undergone menopause within 5 years of natural menopause, to 4 groups: placebo only; placebo and walking (3 times/week at 6 km/h); isoflavone dietary supplementation only (75 mg conjugates/day, equivalent to 47 mg of aglycone, Fujicco Co. Ltd., Kobe, Japan); and isoflavone dietary supplementation and walking. Bone mineral density (BMD) of the lumbar spine, left hip, and whole body were assessed by dual-energy X-ray absorptiometry (DXA), using the Hologic QDR-4500 (Hologic Inc., Waltham, MA), at baseline and at 1 year. There was no difference in height, weight, BMI, and baseline physical activity among the 4 groups. This was also true 1 year after interventions began. Average daily intake of isoflavones from soy foods was approximately 28 mg per day in all 4 groups both at baseline and after 1 year. There were no significant differences in daily intake of isoflavones and other nutrients from the regular diet among the groups at baseline, and between baseline and after 1 year in each group. With regard to the % change in BMD, walking was shown to have a significant effect on preservation of BMD in the hip region after 1 year¹⁴⁾. Interestingly, both interventions showed significant effects on the preservation of BMD in Ward's triangle of the hip after 1 year (Fig. 3).

As an additional benefit, the walking groups showed a significant reduction in body fat percentage in the whole body, trunk region, and legs at 3 to 12 months. Serum HDL-cholesterol concentration also significantly increased from baseline by 7.78% and 8.78% in the walking group and isoflavone plus walking group, respectively. These results suggest that walking exercise prevents an increase in body fat and bone loss in postmenopausal women.

The Exercise and Physical Activity Guide for Health Promotion 2006, which is provided by The Ministry of Health, Labor and Welfare in Japan, recommends 4

Table 2. Recommended Dietary Allowance for Calcium from DRIs for Japanese (2010)⁹⁾

Age	(mg/d)	
	Male	Female
12~14	1000	800
15~17	800	650
18~29	800	650
30~49	650	650
50~69	700	650
70 <	700	600

Table 3. Assessment and Recommendation of Calcium and Vitamins from Guideline for Prevention and Treatment of Osteoporosis 2011⁶⁾

Nutrients	Intake	Source
Calcium	700-800mg/d	Dairy products, Soy, Fish etc. Care should be taken when supplement or calcium medication are provided.
Vitamin D	400~800 Unit/d (10~20 µg/d)	Fish Mushroom
Vitamin K	250~300 µg/d	Natto Vegetables
Protein (reference)	Female: 50g Male: 60g	Meat, Fish, Egg, Bean

Fig. 2 Structures of Estradiol and Soy Isoflavones

Wu et al. *J Bone Miner Res* 21:780-789, 2006Fig. 3 Effects of Exercise and Isoflavone Intake on BMD in Postmenopausal Japanese Women¹⁴⁾

METs·h/week of exercise to prevent lifestyle-related diseases¹⁸⁾. However, our study found that 9 METs·h/week (4 METs × 3/4 h × 3 times/week) are necessary for prevention of fat mass increases and bone mass decreases in postmenopausal Japanese women.

Conclusions

In order to maintain quality of life and extend a person's healthy lifespan, it is important to prevent osteoporosis. Proper amounts of exercise, in conjunction with a diet rich in calcium, vitamins, and protein, and adequate exposure to sunlight, can lower the rates of osteoporosis. It is most effective for young boys and girls to adopt such a lifestyle before reaching the age of peak bone mass. Furthermore, the intake of functional foods on the FOSHU list is a good approach to helping maintain bone health in postmenopausal women.

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