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Effect of Nutrient Intake, Nutritional Status, Physical Activity and Sunlight Exposure on Bone Mineral Density in Women: A Systematic Review

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ABSTRACT: Osteoporosis is a condition or disease that can cause bones to become brittle and break easily. The risk of osteoporosis in women is greater than in men, which is four times greater. Bone mineral density (BMD) or bone density is the total mineral present in bone. Measurement of BMD is important to show the degree of bone mineralization associated with osteoporosis. There are factors associated with reduced bone density. Thus, this systematic review aimed to analyze several factors related to BMD in women including nutrient intake, nutritional status, physical activity, and sunlight exposure. Studies in this systematic review were gathered by the (PRISMA) guidelines and identified through PubMed, Google Scholar, and ScienceDirect databases from 2017 until 2022. A total of 17 articles passed the eligibility and were analyzed in this systematic review. Studies found the effect of nutrient intake, BMI, physical activity, and sunlight exposure on BMD in women from different age groups. So it is necessary to make eating habits with good nutritional intake and have a lifestyle that routinely carries out sufficient physical activity and gets sufficient sunlight to improve and maintain bone health until old age.

KEYWORDS: Bone mineral density, Nutrition, Osteoporosis, Physical activity, Sunlight exposure.

INTRODUCTION

Bone mineral density (BMD) or bone density is the total mineral present in bone. Measurement of BMD is very important to determine the degree of bone mineralization. Osteoporosis requires attention because it can decrease the strength of the bones and increase major fracture risk [1]. The decrease in density and quality of bone structure in osteoporosis is progressive. Osteoporosis is often called the “silent thief” stealing bone mass silently and also the “silent disease” because this disease comes on suddenly, has no obvious symptoms, and is not detected until it comes with fracture complication [2].

Osteoporosis occurs in approximately 200 million worldwide and osteoporosis is more common in postmenopausal women [3]. . The risk of osteoporosis in women is greater than in men, which is four times greater, the prevalence of osteoporosis in women in Indonesia is 23% in the old age group of 50-80 years and 53% in the 70-80 year age group [4]. About 20% of osteoporosis-related fractures die within a year, one third of them must be bedridden, another third must be assisted to walk and only a third can recover and carry out normal activities [4]. Fractures can cause physical, psychological, and social disorders that can affect the quality of life and increase the economic burden [5].

In women, a decrease in bone density occurs after menopause due to decreased levels of estrogen followed by an increase in calcium excretion from the body. Osteoporosis is more potential to occur in women because the protective effect of estrogen during the reproductive years prevents erosion of bone mass, and this protective effect ends in the menopausal period. [6]. The estrogen reaches optimal levels in women of childbearing age. Women need to anticipate the menopausal conditions they will experience after passing reproductive age with an effort to maintain bone mass density. Around the age of 30-40 years, bone remodeling is in balance which in turn determines a person's bone mineral density [7].

Intake of nutrients is very important to increase the degree of bone mineralization. Protein and micronutrients in the form of calcium, vitamin D, potassium, and magnesium play an important role in maintaining bone health [8]. Increasing protein intake can improve bone health which is related to increased BMD and bone turnover [9]. Therefore, maintaining a healthy diet, especially dairy products, is very important for bone health. However, it’s necessary to maintain normal nutritional status, because obesity is related to negative effects on BMD [10].

Calcium and vitamin D are important nutrients in the growth period. Vitamin D is needed in childhood and adulthood, since in the womb (utero), and during the growth period. Inadequate intake of calcium and vitamin D in addition to low physical activity can

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affect peak bone mass [11]. A person who achieves a high peak bone mass will be able to reduce the risk of osteoporosis in the future [9]. Vitamin D deficiency can cause growth retardation and bone deformity, which in old age will increase the risk of bone fracture. Vitamin D deficiency can disrupt calcium homeostasis and reduce bone mineralization [9],[12]. Vitamin D activation can occur with the help of sunlight. Vitamin D deficiency generally occurs in four seasons of countries with less sunshine, but appropriate research shows that deficiency can also occur in tropical countries with two seasons [12].

Based on the background described above, we conducted a systematic review of the published articles. This study aimed to analyze the effect of nutrient intake, nutritional status, physical activity, and sunlight exposure on BMD in women from observational studies.

METHOD

Studies in this systematic review were gathered by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. We conducted the literature search via PubMed, Google Scholar, and ScienceDirect databases from 2017 until 2022. The following search terms were used : ("bone mineral density" OR "bone density") AND ("nutrient intake" OR "nutrition" OR "nutritional status" OR "body mass index" OR "physical activity" OR "sunlight exposure") AND ("women" OR "female") to identify articles which were taken for further analysis. The inclusion criteria used for this study were: (1) articles were published in 2017-2022; (2) articles with observational study design; (3) articles had outcomes to women. Exclusion criteria included: (1) Articles were not in English or Indonesian language; (2) Articles were experimental studies or literature reviews; (3) no access to full-text articles.

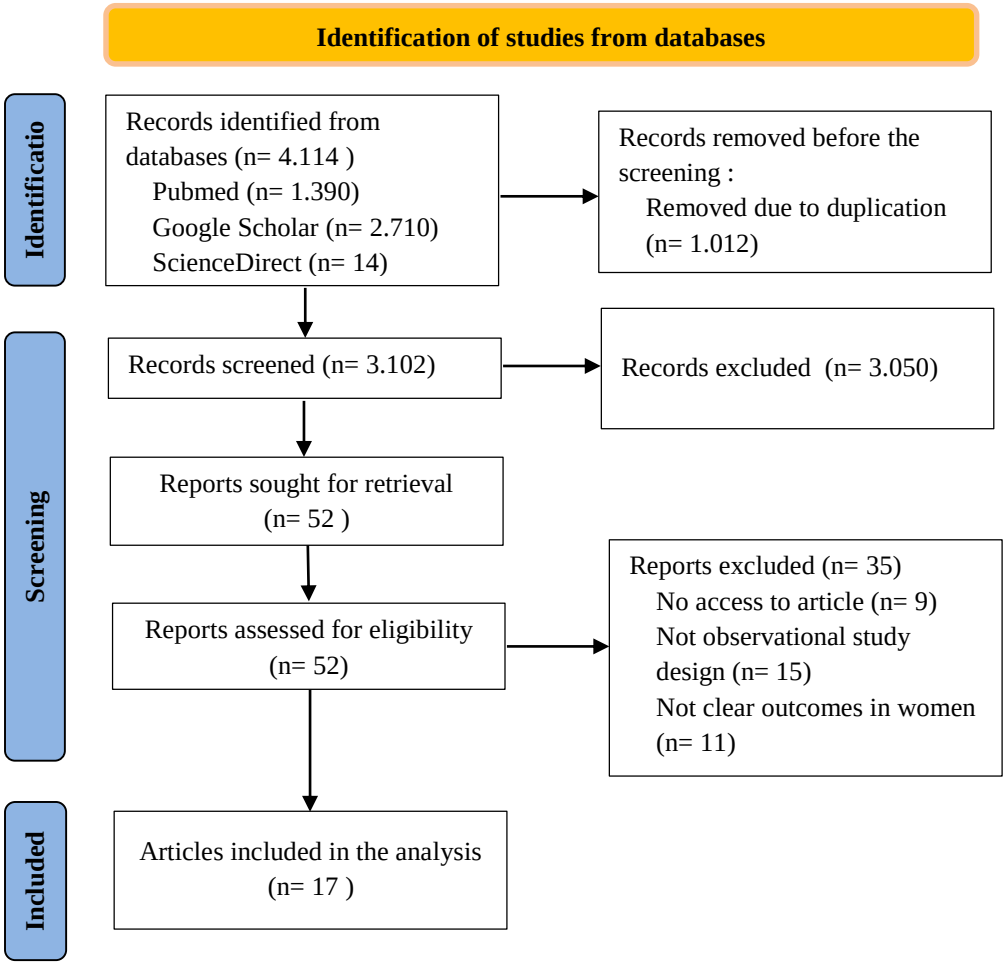

Figure 1. Flow diagram of the studies included in the review. Adapted from PRISMA Flow Diagram.

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RESULT

The results of the literature search identified 4.114 potential studies based on the search term used. After excluding the duplicates, the title of 3.102 articles was screened. A total of 52 articles were assessed for eligibility. There are 17 articles that passed the eligibility criteria and were analyzed in this study.

Table 1. Elaboration of the articles analyzed

No	Authors	Theme	Study Design	Participants	Outcome Assessed	Results
1.	Pham et al., 2018 [13]	Effect of physical activity and calcium intake on the BMD of older people	Prospective longitudinal Study	1683 women and 1010 men over 50 years old in Dubbo City, Australia	BMD, fracture, physical activity, dietary calcium intake, cigarette smoking.	Women with a fracture had physical activity index lower than women without a fracture. Greater dietary calcium intake was related to higher BMD of the femoral neck, meanwhile, more cigarette intake was related to lower BMD of the femoral neck in men and women.
2.	Méndez-Gallegos et al., 2018 [14]	Measurements of the relationship of dietary intake, BMI, reproductive factors, and BMD in Adult Women	Prospective longitudinal Study	40 women of reproductive age from the first study conducted 12 years ago in Sonora, Mexico, were divided into 3 groups: nulliparous, first-time mothers 12 years ago and nulliparous 12 years ago	BMD, protein intake, phosphorus intake, calcium intake, fat intake, BMI, age, age at menarche, number of children, and duration of breastfeeding.	Age was associated with BMD as indicated by higher BMD values on current measurements of the lumbar spine and total femur than initial values 12 years ago ($p \leq 0.05$). A positive correlation in BMI to BMD was found in G2 ($p < 0.05$), meanwhile BMD inversely correlated with age at menarche in G1 ($p < 0.01$).
3.	Alay et al., 2020 [15]	Effect of BMI, menopausal symptoms, and lipid profile on BMD in Postmenopausal Women	Case-control Study	452 postmenopausal women in Turkey	BMD, waist circumference, BMI, postmenopausal symptoms, lipid profile	L2-L4 BMD had a negative correlation with LDL, but a positive correlation with waist circumference. BMI was positively correlated with BMD of the femur neck and lumbar spine. Heart discomfort of menopausal symptoms had a negative correlation with L1-L2 BMD.
4.	Al-khammash et al.,	Nutrients related to BMD in postmenopausal women	Case-control Study	200 postmenopausal women in Jordan consist of 100	BMD, macronutrients and micronutrients intakes	Carbohydrates, vitamin B6 and phosphorus intake had a protective effect.

	2022 [16]			osteoporosis women and 100 controls.		Iron, potassium, magnesium, fiber, and zinc were protective in Q3 and Q4. Vitamin C, fats, and monosaturated fats had protective effects in Q4.
5.	Groenendijk et al., 2022 [17]	Effect of protein intake on BMD in older adult	Cross-sectional study	1570 participants aged ≥65 years old in four published trials	BMD, protein intakes	Higher total protein intake and protein intake from animal sources were associated with higher BMD. Protein intake from plant sources was associated with lower BMD.
6.	Ilesanmi-oyelere et al., 2019 [18]	Effect of nutrient patterns on BMD in postmenopausal women	Cross-sectional study	101 postmenopausal women aged 54-81 years in New Zealand	BMD, BMI, dietary intake and nutrient pattern	Calcium, protein, riboflavin, and niacin intakes were positively correlated with spine BMD. High riboflavin, phosphorus, and calcium intakes had a positive correlation with spine and femoral BMD, while high vitamin E, α-tocopherol, β-carotene and omega 6 fatty acid intakes had a negative correlation with hip and trochanter BMD.
7.	Desrida et al., 2017 [19]	Effect of Physical Activity, Vitamin D and Calcium Intakes on BMD in adolescent girls	Cross-sectional study	148 female adolescents in Tilatang Kamang, Agam district.	Bone mineral density (BMD), physical activity level, vitamin D intake and calcium intake	Physical activity, calcium and vitamin D intake correlated with the BMD of female adolescents ($p<0.05$).
8.	J. S. Kim et al., 2021 [20]	Association between milk consumption and BMD	Cross-sectional study	8539 subjects aged ≥20 years in South Korea	BMD, frequency of milk consumption, calcium intake.	Postmenopausal women with the frequency of milk consumption 2-6 times a week were associated with higher BMD and lower risk of osteoporosis ($p=0.044$, OR=0.23 ; 95% CI)
9.	J. H. Lee et al., 2021 [21]	Effect of milk intake and physical activity on BMD	Cross-sectional study	1061 adolescents aged 13- 18 years in South Korea	BMD, milk intake, physical activity	In females, the group with milk intake and higher physical activity had higher lumbar BMD. The group with no milk intake and low physical activity had lower OR for higher BMD,

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						compared to the group with milk intake and high level activity.
10.	Kopiczko, 2020 [22]	Effect of physical activity, nutrition, and sunlight exposure on BMD	Cross-sectional study	500 women >40 years old in Augustow and Warsaw, Poland	BMD, BMI, calcium intake, vitamin D intake, physical activity, sun exposure	Premenopausal hormonal status, sufficient and high present physical activity, and sufficient past and present sun exposure were related to BMD in the distal part of the forearm. Meanwhile, the proximal part was affected by high physical activity both in the past and present, sunlight exposure in the past and present, and recommended calcium and vitamin D intake.
11.	Soomro et al., 2017 [23]	Frequency of osteopenia and associated risk factors among young female students	Cross-sectional study	100 female students aged 20-30 years	BMD, sunlight exposure, menstrual status, physical activity, vitamin D and calcium intake.	Students who had normal bone density were 30% meanwhile osteopenic students were 70%. Factors significantly associated with osteopenia in female students were residence ($p<0.01$) and sunlight exposure ($p<0.01$).
12.	H. J. Lee et al., 2021 [24]	Association between sunlight exposure and fractures in elderly	Cross-sectional study	638 patients (560 women and 78 men) with osteoporosis ≥65 years in South Korea	BMD, fracture, BMI, daily sunlight exposure, current smoking, monthly alcohol intake, daily calcium intake and physical activity	The fracture group had lower femoral neck BMD, physical activity, sunlight exposure and daily calcium intake ($p<0.05$). The group who had sunlight exposure ≥5 hours had 0.55 times lower OR of total fractures than the group with exposure <5 hours.
13.	(Wang et al., 2022 [25]	Association between Body Composition and Bone Mineral Density	Cross-sectional study	90 female employees aged 37-85 years at the University of Tai'an	BMD, BMI and body composition	There were positive correlations between BMI, trunk muscle mass, upper and lower limb muscle mass, skeletal muscle mass, whole body phase angle and L1-4 BMD.
14.	Mazocco & Chagas, 2017 [26]	Association between BMI and Osteoporosis	Cross-sectional study	393 postmenopausal women in Brazil	BMD, BMI	In the normal weighted group, the prevalence ratio for osteoporosis was twice the prevalence ratio for obese women

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						Overweight women had a prevalence ratio for osteoporosis of 1.7 times higher than obese women.
15.	Hemmati et al., 2021 [27]	Prevalence of osteoporosis and the affecting factors	Cross-sectional study	850 postmenopausal women aged 50-65 years in Iran	BMD, age, menopausal age, BMI, arm circumference, physical activity	The prevalence of primary osteoporosis in the lumbar vertebra, and femur neck was 23,4% and 3.4%. Risk factors of osteoporosis in postmenopausal women were age, menopausal age, BMI, arm circumference, education level, housing status and marital status
16.	H. Y. Kim et al., 2017 [28]	Effect of abdominal obesity on BMD	Cross-sectional study	1.138 postmenopausal women in South Korea	BMD, BMI, waist circumference, skeletal muscle mass and body fat mass	The osteoporotic group had lower weight, BMI, waist circumference, skeletal muscle mass and body fat mass than the normal BMD group. In the group with a short postmenopausal period, women with abdominal obesity had a lower risk of osteoporosis.
17.	Li, 2022 [10]	Effect of obesity on BMD	Cross-sectional study	2218 obese adults aged 40-59 years	BMD, BMI	BMI and lumbar BMD had a positive correlation and an inverted U-shaped association was identified. For subjects with BMI< 50 kg/m^2, an increase in BMI was related to higher BMD, however for subjects with BMI >50 kg/m^2, an increase in BMI was related to lower BMD.

DISCUSSION

This study systematically reviewed 17 studies that used some observational study design including prospective longitudinal study, case-control, and cross-sectional study to see the effect of nutrients intake, nutritional status, physical activity and sunlight exposure on BMD focusing on women. The risk of osteoporosis in women is greater than in men [4]. Osteoporosis is more common in women in old age because women after menopause experience increased bone resorption due to reduced levels of the hormone estrogen [29]. Measurement of BMD is important to show the degree of bone mineralization associated with osteoporosis. Bone mineral density (BMD) or bone density is the total mineral present in bone. The World Health Organization (WHO) makes criteria for BMD based on a measurement, a T-score ≥ -1 SD is normal, a T-score between -1 SD and -2.5 SD is categorized as osteopenia, and a T-score ≤ -2.5 SD categorized osteoporosis [30].

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Nutritional intake is needed to optimize BMD and prevent osteoporosis. Pham et al [13] conducted a prospective longitudinal study and reported that higher dietary calcium intake was related to higher BMD and lower risk of fracture. Furthermore, the study conducted by Desrida et al [19] showed a positive relationship between calcium and vitamin D intake on BMD in adolescent girls. In addition, Kopiczko [22] suggested that sufficient dietary calcium and vitamin D intake was essential factor in bone tissue mineralization. Approximately 80-90% of bone contains minerals that are mainly filled with minerals calcium and phosphorus, so calcium had a major role in the occurrence of osteoporosis [31]. The balance of calcium in the body is determined by the parathyroid hormone. If the calcium in the blood is normal, then the process of mineralization and demineralization takes place in balance. Low calcium intake accompanied by a decreased ability of the body to absorb calcium which generally occurs after menopause can cause a decrease in BMD [12].

Mineral Calcium is more contained in milk and dairy products. Cow's milk contains about 120 mg/100g of calcium [9]. In addition, calcium is also found in non-dairy products such as fish, eggs, green vegetables, tofu, soybeans, and shellfish [32]. Kim et al [20] conducted a study on South Korean adults, which showed that the frequency of milk consumption was related to high BMD and reduced risk of osteoporosis. Furthermore, Lee et al [21] examined the effect of both milk intake and physical activity in combination on BMD also in South Korean adults. The result was that medium to tough physical activity combined with the consumption of milk was related to BMD and supported bone health [21]. Calcium intake will affect bone compression during the growth period and will affect the peak bone mass which can occur from the early age of 17-18 years to the end of the age of 35 years. Most of the bone mass will accumulate at the end of adolescence age both in men and women [12].

Additionally, not only calcium but other nutrients are also related to bone density. Al-Khammash et al [16] carried out a case-control study in postmenopausal women and showed that a poor diet that lacks carbohydrates, protein, fat, and water can reduce bone density, furthermore diet which is rich in ß-carotene, vitamin B6, C, E, Fe, Mg, Zn, Na, and phosphorus, had a preventive effect against osteoporosis. Groenendijk et al [17] found that great protein intake from animal sources was related to great BMD. Increasing protein intake by 0.8-0.9 g/kg/day through the recommendation in certain conditions is beneficial for bone health because can increase BMD and bone turnover so which can lower the risk of fractures. Adequate protein is essential to maintain adequate BMD and strong muscle mass [9].

Vitamin D is very essential for maintaining bone health. Vitamin D regulates calcium and phosphorus to be available in the blood in the process of bone formation. Vitamin D in the body is mainly obtained from skin synthesis which begins with exposure to ultraviolet B, besides that vitamin D can also be obtained from foods but in a smaller amount [33]. Lee et al [24] found an association between sunlight exposure with exposure duration ≥5 hours a day with a lower risk of fracture in patients with osteoporosis. Kopiczko [22] conducted a study on adult polish women and found that adequate past and present exposure to sunlight were the factors that significantly affect bone mineralization. Meanwhile, the study by Soomro et al [23] showed that osteopenia was quite common in the age group less than 25 years, with little exposure to sunlight, low physical activity, and inadequate dietary intake of calcium and vitamin D. Vitamin D was mainly obtained from sunlight, intake of food sources, supplementation and food intake fortification [12].

Vitamin D is often named the 'sun vitamin' in case it needs sunlight to metabolize it. Several recent studies have shown an increased vitamin D deficiency even in countries with sufficient sunshine. The cause of the deficiency is probably due to the influence of changes in lifestyle or food intake [12]. Several factors affect the skin's ability to synthesize vitamin D from exposure to sunlight such as UV index, season, skin pigmentation, and age. Vitamin D formed in the skin can is better than vitamin D obtained from food because it lasts twice. Exposure to sunlight on the skin from the arms to the face for at least 30 minutes until the midday sun will suffice. Sun exposure of 10-15 minutes is sufficient for Asians at 11.5 LU whereas at 29 LU it takes 10-45 minutes with a longer duration in winter [34]. Vitamin D in food is mainly in the shape of vitamin D3 and its metabolism is in the form of 25(OH)D3. Vitamin D from food is mainly found in animal sources in the form of cholecalciferol. The sources are fatty fish (such as salmon, tuna, and mackerel) and liver oils from fish. Little sources of vitamin D are in the liver, cheese, and egg yolks [9].

The way to determine a person's nutritional status is by anthropometric measurements, one of which is by assessing the body mass index (BMI). Some works of literature have studied the relationship between BMI and BMD. Méndez-Gallegos et al [14] conducted a prospective longitudinal study that found a relationship between BMI and BMD with a positive correlation in a group of first-time mothers 12 years ago. In addition, the study by Wang et al [25] showed an association between BMI and L1-4 BMD positively correlated. Several studies show obesity is a protective factor against osteoporosis. Hemmati et al [27] found that people with a high BMI will be at lower risk of osteoporosis. The prevalence of osteopenia and osteoporosis was lower in obese women [26]. The study

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of Kim et al [28] in postmenopausal period Korean women had the result that in the women with a short menopausal period, the group with abdominal obesity has a lower risk of developing osteoporosis than those without abdominal obesity. However, Li et al [10] identified an inverted U-shaped relationship between BMI and BMD. For subjects with BMI< 50 kg/m^2, an increase in BMI was related to an increase in BMD, however for subjects with BMI >50 kg/m^2, an increase in BMI was related to a decrease in BMD [10].

An evaluation of the effect of obesity on BMD highlighted that increasing BMI helps support body weight [9]. Excess body weight can cause metabolic changes in the form of insulin resistance and excessive production of androgen and estrogen hormones thereby reducing osteoblast action. Besides that, overproduction of adipokines or leptin levels due to high fat consumption may contribute to gained calcium absorption [35]. However, excessive subcutaneous fat and visceral fat can increase systemic inflammation which can trigger bone loss, besides that it is associated with increased levels of proinflammatory cytokines such as TNF and IL-6 which can promote bone resorption and increase the risk of osteoporosis [26].

Physical activity has good benefits for individual health, including bone health. Desrida et al [19] had a study that resulted in an association between the level of physical activity and the bone density level of female adolescents. Young women with less active physical activity had a 36.64 times chance of having an abnormal bone density level compared to young women with active physical activity [19]. Furthermore, in females, Lee et al [21] found that the group with milk intake and high-level physical activity had higher BMD. Meanwhile, Kopiczko [22] examined BMD and physical activity of women aged >40 years and the results showed the effects of past and present activity on BMD. Women with a fracture had physical activity index lower than women without a fracture [13].

The poorer the physical activity, the higher the risk of decreasing BMD. Lack of physical activity accelerates bone mass to be lost, while exercise bears the weight of the body and increases bone mass. For osteoporosis patients, the recommendations for an exercise program focused on maintaining a balance of posture, coordination, and stabilization of the hips and trunk. The recommended exercise for children and adolescents is at least 40 minutes of high-intensity, short-duration physical activity such as running or walking [9]. Exercise can increase the peak bone mass in adolescent and prepubertal girls [36]. High peak bone mass is essential for future bone health. The higher the peak bone mass gained, the lower the risk of osteoporosis. Sufficient physical activity will be very useful for lessening the risk of fractures by increasing BMD and reducing the risk of falling [9].

This review has the strength of focusing on women who are a group that is more susceptible to osteoporosis, as well as subjects from several age groups. This review also has limitations in the form of studies reviewed which are limited to observational studies and do not include experimental studies. Despite our limitations, this review provides useful knowledge regarding factors associated with BMD.

CONCLUSION

Bone mineral density (BMD) is important in relation to osteoporosis. Optimizing bone density from an early age can lessen the risk of osteoporosis and fractures in the future. Factors such as nutrient intake, nutritional status, physical activity, and sun exposure affect BMD. So it is necessary to make eating habits with good nutritional intake and have a lifestyle that routinely carries out sufficient physical activity and gets sufficient sunlight to improve and maintain bone health until old age. So we recommend further research in the future focusing on knowing more factors that affect BMD so that it can provide efforts to prevent osteoporosis.

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