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REVIEW

Vitamin D inadequacy in postmenopausal women in Eastern Asia

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ABSTRACT

Objective: To review data on the prevalence of vitamin D inadequacy and its causes in postmenopausal women in Eastern Asia.

Research design and method: Data were obtained from the published biomedical literature as well as abstracts and posters presented at scientific meetings. Using MEDLINE, EMBASE and BIOSIS databases (to July 2007), epidemiological studies were identified using the search terms: 'human', 'vitamin D', 'vitamin D deficiency', 'vitamin D inadequacy', 'vitamin D insufficiency' and 'hypovitaminosis D', 'osteomalacia' and 'osteoporosis'. Additional references were also identified from the bibliographies of published articles.

Results: The prevalence of vitamin D inadequacy in studies of postmenopausal women (ambulatory or with osteoporosis or related musculoskeletal disorders) in Eastern Asia ranged from 0 to 92%, depending on the cut-off level of serum 25-hydroxycholecalciferol [25(OH)D] that was applied (range ≤6–35 ng/mL [≤ 15–87 nmol/L]). One large international study found that 71% of postmenopausal women with osteoporosis in Eastern Asia had vitamin D inadequacy, defined as serum levels of 25(OH)D < 30 ng/mL (75 nmol/L). Prevalence rates using this cut-off level were 47% in Thailand, 49% in Malaysia, 90% in Japan and 92% in South Korea. High prevalences of vitamin D inadequacy were evident in two studies using a lower 25(OH)D level cut-off value of < 12 ng/mL (30 nmol/L) – 21% in China and 57% in South Korea. Dietary deficiency and inadequate exposure or reactivity to sunlight (due to lifestyle choices, cultural customs and/or aging) were identified as important risk factors for vitamin D inadequacy.

Conclusions: Non-uniform, epidemiological studies indicate a high prevalence of vitamin D inadequacy in postmenopausal women in Eastern Asia. Recommended remedial approaches are education campaigns and broad-based provision of vitamin D supplementation.

Introduction

Vitamin D is a pro-hormone that plays a vital role in metabolic processes and ultimately the preservation of human health. Vitamin D is required to maintain optimal blood levels of calcium and phosphate, which are needed for normal mineralization of bone, muscle contraction, nerve conduction and general cellular function[1-3].

Well known as the cause of rickets in children, vitamin D inadequacy is increasingly being recognized as an established risk factor for the development of osteoporosis and osteomalacia in adults. It has also been linked, controversially in some cases, with several other diseases in adults, including diabetes mellitus, heart disease, hypertension, stroke and certain types of cancer[4,5].

Osteoporosis and osteomalacia are risk factors for hip and other fractures, and thus are underlying causes of death and disability in the elderly[6,7]. Inadequate levels of vitamin D have been shown to be present in the majority of patients hospitalized with hip and extremity fractures[8]. The role that vitamin D plays in maintaining optimal neuromuscular function has been demonstrated in studies showing that vitamin D supplementation improves reaction time and balance, which are important in maintaining the agility to avoid falls and hence skeletal fracture[9,10].

Given the crucial role of vitamin D in the maintenance of musculoskeletal integrity, and evidence from large epidemiological studies that vitamin D inadequacy is present in many postmenopausal women in European and North American countries[11-15], we reviewed the biomedical literature to assess the prevalence of vitamin D inadequacy among postmenopausal women in Eastern Asia. We also attempted to identify the factors contributing to vitamin D inadequacy within this particular population and propose corrective strategies.

Methods

Aim

The aim was to review data on the prevalence of vitamin D inadequacy and its causes in postmenopausal women in Eastern Asia via a comprehensive search of the biomedical literature.

Data sources

Biomedical literature published in any language or presented at international or regional conferences as abstracts or posters between 1 January 1980 and 5 July 2007 were used as data sources. Where available, data from fully published papers were preferred. Additional references were identified from the reference lists of published articles.

Search strategy

MEDLINE, EMBASE and BIOSIS databases were searched using the terms: 'human', 'vitamin D', 'vitamin D deficiency', 'vitamin D inadequacy', 'vitamin D insufficiency', 'hypovitaminosis D', 'osteomalacia' and 'osteoporosis' or their equivalents. Searches were last updated 5 July 2007.

Selection criteria

Studies that determined the vitamin D status of postmenopausal women in countries of Eastern Asia, specifically Burma, Cambodia, China, Hong Kong, Indonesia, Japan, Laos, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand and Vietnam were selected.

Results

Epidemiology of vitamin D in Eastern Asia

Our search identified 12 studies (spanning a 17-year-period) that assessed vitamin D status in a total of 2455 postmenopausal women, who were either ambulatory or had osteoporosis or related musculoskeletal conditions, in China, Hong Kong, Japan, Malaysia, South Korea and Thailand[16-28]. One of the studies, a recent, multi-national (18 countries) epidemiological study involving a total of 2589 community-dwelling postmenopausal women with osteoporosis reported data from 549 women from 4 Eastern Asian countries – South Korea, Japan, Thailand and Malaysia[29]. We were unable to identify epidemiological data for Burma, Cambodia, Laos, Indonesia, Philippines, Singapore and Vietnam.

The vitamin D status of ambulatory postmenopausal women (n = 1240) from the 12 studies identified is summarized in Table 1[19,20,22,24-26,28] and that for women with osteoporosis or related musculoskeletal conditions (n = 1215) is summarized in Table 2[16-18,21,23,27].

In the 12 epidemiological studies, prevalence rates for serum hydroxycholecalciferol [25(OH)D] levels below a cut-off of ≤6–35 ng/mL (15–87 nmol/L) ranged from 0 to 92% (mean 36%) Most of these studies reported a high prevalence of serum 25(OH)D levels below the specified threshold values, a breakdown of which is as follows:

- 0–57% (mean: 13.5%) in 4 studies applying threshold values ≤ 12 ng/mL (≤ 30 nmol/L);
- 8–71% (mean: 33%) in 4 studies applying threshold values of 13–20 ng/mL (32–50 nmol/L) and

Table 1. *Vitamin D status in ambulatory postmenopausal women in Eastern Asian countries*

Location	Study Ref.	No. of subjects	Mean age (years)	Mean serum 25(OH)D (ng/mL)	Serum 25(OH)D cut-off (ng/mL)	Subjects below cut-off (%)	Assay method	Season	Population
China	28	48*	66.9	17.2	10 12	15 21	RIA (Incstar) 9%†	Winter	Healthy volunteers
Japan	19	151‡	66.5	24.0	12 15	5 8	HPLC 5.6%†	Winter	Healthy ambulatory
South Korea	20	276	ND	12.2	6 12	11 57	ND	Winter	Healthy ambulatory
	24	263	ND	25.2 (10%)§ 13.9 (48%)§ 7.8 (36%)§ 3.2 (6%)§	ND	ND	RIA	Winter	Healthy
Malaysia	22	101, Malay	60	17.8	20	71	RIA (Gamma B)	ND	Healthy volunteers
		173, Chinese	59	27.6	20	11			
Thailand	26	98	50	32.6	35	60	RIA (DiaSorin)	ND	Early postmenopausal
	25	130	71.6	44.9	35	15	RIA (DiaSorin)	ND	Rural community

ND = no data available; HPLC = high-performance liquid chromatography; RIA = radioimmunoassay

*25(OH)D levels also measured in 'young' women (mean age 30.9 years; $n = 48$), 'young' men (31.3 years; $n = 48$) and 'old' men (68.9 years; $n = 50$)

†Inter-assay coefficient of variation (CV)

‡Peri- and postmenopausal women (age range: 46–82 years)

§Percentage of individuals with normal, mild, moderate and severe mean 25(OH)D levels

Table 2. *Vitamin D status in postmenopausal women with osteoporosis or other musculoskeletal conditions in Eastern Asian countries*

Location	Study Ref.	No. of subjects	Mean age (years)	Mean serum 25(OH)D (ng/mL)	Serum 25(OH)D cut-off (ng/mL)	Subjects below cut-off (%)	Assay method	Population
Hong Kong	17	107*	Range 70–93	17.1	ND	ND	CPBA	Hip fracture
		31	Range 49–70	17.8	ND	ND		
	21	44	78.1	17.6	20	50	CPBA	Hip fracture
Japan	18,23	198	68.4	20.6	9	0	CBCI	Osteoporosis
					20	47		
					30	90		
South Korea	16	378	ND	ND	20	22	RIA	Normal; osteopenia; osteoporosis
	18,23	101	65.9	17.6	9	12	CBCI	Osteoporosis
					20	64		
					30	92		
Malaysia	18,23	150	67.0	30.2	9	1	CBCI	Osteoporosis
					20	11		
					30	49		
Thailand	18,23	100	67.1	30.3	9	0	CBCI	Osteoporosis
					20	12		
					30	47		
	27	106	69.4	33.3	25	11	RIA (DiaSorin) 9.4–11.0%†	Normal; osteopenia; osteoporosis
					30	35		
					35	65		

ND = no data available; CPBA = competitive protein binding assay

CBCI = competitive binding chemiluminescence immunoassay; RIA = radioimmunoassay

*25(OH)D levels also measured in women aged < 70 years ($n = 31$) and men aged < 70 years ($n = 28$) and ≥ 70 years ($n = 32$)

†Inter-assay coefficient of variation (CV)

- 11–92% (mean: 51.6%) in 4 studies applying threshold values of 21–35 ng/mL (52–87 nmol/L).

China/Hong Kong

Vitamin D inadequacy occurs in all regions in China, but is more common in the north where long, cold winters contribute to lack of sunshine exposure[30]. Additionally, dietary vitamin D intake in China is low at 1 µg/day (40 IU/day)[30]; this compares with a vitamin D intake among Australians of 2.6–3.0 µg/day (104–120 IU/day) for men and 2.0–2.2 µg/day (80–88 IU/day) for women[31]. The low dietary intake in China is thought to be due to low consumption of dairy products in the diet. Vitamin D-rich foods such as fatty fish, eggs and chicken liver are seldom consumed, particularly by elderly Chinese, whose diet is mainly composed of vegetables, lean meat and rice[32].

A cross-sectional study evaluated vitamin D status in a total of 198 male and female healthy volunteers in north-east China[28]. Among 48 women aged 65–75 years (mean age 67 years), 15% and 21% had 25(OH)D levels of < 10 ng/mL (< 25 nmol/L) and < 12 ng/mL (< 30 nmol/L), respectively. The study was carried out in Shenyang (latitude: 41° North), which has long, dark winters, and a population with a low dietary intake of vitamin D. Shenyang also has a polluted atmosphere due to heavy industry, thus reducing levels of incident sunlight[28].

A similar situation also prevails in Hong Kong where, despite the sub-tropical climate and geographical location at latitude 22° North, the primary causes of vitamin D inadequacy in postmenopausal women are also a diet low in vitamin D content and a lack of exposure to sunlight[33]. An interview survey of 547 middle-aged and elderly Chinese women living in Hong Kong confirmed that many women (62.3%) actively avoid sunlight exposure by staying indoors and using sunscreen products and parasols, including those who were aware of the role of sunlight as a 'source' of vitamin D and that vitamin D was beneficial for bone health[34]. Low vitamin D levels were observed in a recent study conducted in 382 community-dwelling Hong Kong Chinese (mean age 69 years; no gender breakdown reported), which found that 23% of subjects had 25(OH)D levels < 20 ng/mL (< 50 nmol/L); the proportion increased to 63% for levels < 30 ng/mL (< 75 nmol/L)[33]. This study also found an association between serum 25(OH)D levels < 30 ng/mL and secondary hyperparathyroidism, which conferred an increased risk of osteoporotic fractures and falls[33].

A Hong Kong study among 198 female and male hip fracture patients aged 49–93 years found that serum 25(OH)D levels were significantly ($p < 0.01$) lower than in age- and sex-matched control groups[17]. The control group (individuals aged 60–90 years living in the community) had mean 25(OH)D levels of 27.0 ng/mL (67 nmol/L). Mean 25(OH)D levels were significantly lower in women than in men (17.5 vs. 20.5 ng/mL or 44 vs. 51 nmol/L; $p < 0.01$). Hip fracture patients with a low 25(OH)D level were less ambulant and went outdoors less frequently than hip fracture patients with a normal 25(OH)D level[17].

Another study of vitamin D status among elderly women with hip fracture in Hong Kong found substantial evidence of vitamin D inadequacy, with over 50% of patients having a serum 25(OH)D level < 20 ng/mL (< 50 nmol/L)[21]. The mean serum 25(OH) D level was 17.6 ng/mL (44 nmol/L). Patients with serum levels < 20 ng/mL (< 50 nmol/L) and hip fracture were characteristically home-bound and/or institutionalized, with a smaller living environment and limited access to open space. The authors commented that the association of vitamin D inadequacy with muscle weakness may contribute to falls, and account for the increased rate of hip fractures compared with controls that was observed in this study[21].

Japan

Older Japanese people with low levels of daily activity and diets low in vitamin D are at highest risk of vitamin D inadequacy[19,35,36]. The prevalence of 25(OH) D levels < 15 ng/mL (< 37 nmol/L) was 8% among 151 healthy rural-living women of mean age 66.5 years, many of whom engaged in farm work and consumed a lot of fish and eggs[19]. In contrast, a 60% prevalence of 25(OH)D levels < 12 ng/mL (< 30 nmol/L) was found in 133 female and male nursing home residents (mean age 84.6 years) who were physically dependent and had diets low in vitamin D[36]. An inactive lifestyle and low fish consumption were predictors of low 25(OH)D levels in a later study of 263 frail female and male elderly (mean age 82.9 years) requiring home care in whom there was a 15–20% prevalence (depending on season) of 25(OH)D levels < 12 ng/mL (< 30 nmol/L)[35].

Assuming that physical inactivity (and hence reduced sunlight exposure) and vitamin D-poor diets have become increasingly common in everyday life in Japan, it is perhaps not surprising that the large multi-national study found that 90% of the 198 postmenopausal Japanese women with osteoporosis (aged 41–96 years) had 25(OH)D levels < 30 ng/mL (< 75 nmol/L) (Figure 1)[29].

Malaysia

The authors of the only Malaysian study identified, which found that 71% of Malay women aged

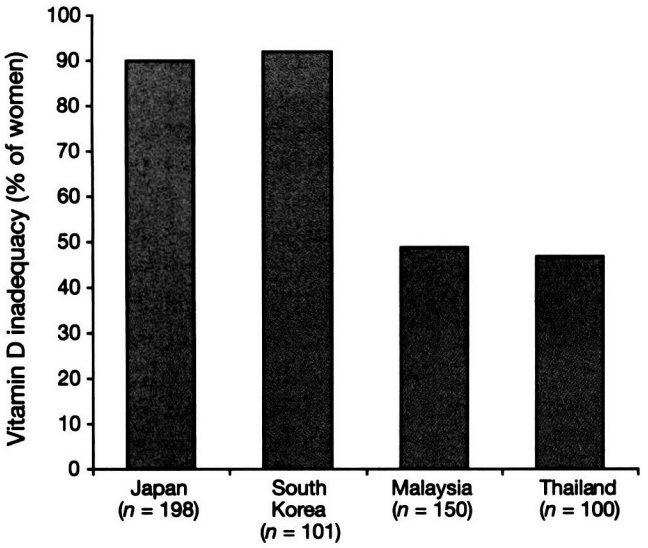

Figure 1. *Prevalence of vitamin D inadequacy (defined as 25[OH]D levels < 30 ng/mL [< 75 nmol/L]) in a total of 549 postmenopausal women with osteoporosis in 4 Eastern Asian countries*[29]

50–65 years have 25(OH)D levels between 10 and 20 ng/mL (25–50 nmol/L), concluded that a high prevalence of vitamin D inadequacy among older women represented an important public health issue, warranting development of a remedial strategy[22]. Mean 25(OH)D levels were significantly lower among Malay than Chinese women (18 ng/mL [45 nmol/L] vs. 28 ng/mL [70 nmol/L], $p < 0.05$)[22]. The high prevalence of vitamin D inadequacy among postmenopausal Malaysian women with osteoporosis was confirmed by data from the multi-national study, which found that 49% of the Malaysian cohort ($n = 150$) had 25(OH)D levels < 30 ng/mL (Figure 1)[29].

South Korea

Studies of postmenopausal women in South Korea indicate a high prevalence of vitamin D inadequacy in this country, which is located at latitude 37° North (Seoul) and has a temperate climate of four distinct seasons[16,20,24,37]. Around 90% of 263 postmenopausal Korean women in one study were found to have 25(OH) D levels < 25 ng/mL (< 62 nmol/L) and 42% of the women had moderate or severe vitamin D deficiency, defined as 25(OH)D levels ≤ 8 ng/mL (≤ 20 nmol/L)[24]. Another study of 378 postmenopausal Korean women found that 22% had serum 25(OH)D levels ≤ 8 ng/mL (≤ 20 nmol/L)[16]. The prevalence of osteopenia or osteoporosis in this study was significantly ($p < 0.05$) higher among women with vitamin D inadequacy than in those with normal vitamin D levels[16]. In another study[20], which found 25(OH)D levels ≤ 12 ng/mL (≤ 30 nmol/L) in 57% of 276 healthy ambulatory postmenopausal women in Seoul, significantly ($p < 0.05$) lower bone mineral density was apparent in women with vitamin D inadequacy compared to those with normal vitamin D levels. These authors advocated supplemental vitamin D treatment for the majority of postmenopausal women, particularly during the winter season[20]. In the South Korea cohort ($n = 101$) of the multinational study[29], the prevalence rates for 25(OH) D levels of < 9 ng/mL (< 22 nmol/L), < 20 ng/mL (< 50 nmol/L) and < 30 ng/mL (< 75 nmol/L; defined as vitamin D inadequacy) were 12%, 65% and 92%, respectively (Figure 1).

The effects on vitamin D levels of seasonal variations in daylight, time spent outdoors and dietary vitamin D intake were investigated in 179 Korean women aged 20–75 years[37]. The mean serum level of 25(OH) D was 23 ng/mL (57 nmol/L) and 16.5% of subjects had vitamin D inadequacy defined as < 10 ng/mL (< 25 nmol/L). Low 25(OH)D levels were correlated with low vitamin D intake ($p < 0.0001$), less time spent outdoors ($p < 0.01$) and the winter season ($p < 0.0001$). The investigators concluded that Korean women have low levels of vitamin D compared with women in countries with geographical locations and weather that afford longer hours of sunlight and countries with vitamin D-rich diets (either through fortification of foods or high consumption of dairy products)[37].

Taiwan

A survey of 262 Taiwanese women aged 40–72 years (including 67 who were menstruating), found that the prevalence of vitamin D inadequacy (defined as 25(OH)D levels < 30 ng/mL [<75 nmol/L]) was almost 50%[38]. However, the authors commented that the real prevalence of vitamin D inadequacy in Taiwan may be higher, since the survey did not include very elderly women (those aged > 70 years), for whom dietary vitamin D, sunlight exposure, intestinal absorption of vitamin D and skin synthesis of vitamin D are generally particularly low[38].

Thailand

The assumption that there is adequate sunlight in Thailand to ensure sufficient vitamin D production appeared to have been confirmed by a study conducted in 1996 that determined mean levels of serum 25(OH)D of 42 and 67 ng/mL (60 and 167 nmol/L), respectively, among 158 men and women aged 20–80 years[39]. However, more recent analyses suggest otherwise[25–27].

In 106 urban-living elderly women (mean age 69.4 years), the majority of whom had osteopenia

(n = 40) or osteoporosis (n = 39), 65% had 25(OH) D levels < 35 ng/mL (< 87 nmol/L), which the authors surmised might be due to high ambient temperatures (encouraging indoor living) and poor skin reactivity to UV light among the elderly[27]. In a comparison of data from this urban-living population with data from 130 rural-living postmenopausal women (mean age 71.6 years), the same investigators demonstrated a significantly higher prevalence of 25(OH)D levels < 35 ng/mL (< 87 nmol/L) among urban versus rural women (65% vs. 17%; $p < 0.001$)[25]. They concluded that more time spent outdoors and higher levels of physical activity in the rural elderly are important factors for maintaining optimal vitamin D levels. In another analysis of the data from urban- and rural-living postmenopausal women plus data from 98 early postmenopausal women (mean age 50 years)[26], the respective percentages of women with 25(OH)D levels < 35 ng/mL (< 87 nmol/L) were 65%, 15% and 60%. The surprisingly high rate of vitamin D inadequacy in the early postmenopausal group suggests that the risk for developing osteoporosis exists soon after the onset of menopause[26]. In the Thai cohort of the multinational study (n = 100), the prevalence of vitamin D inadequacy, defined as < 30 ng/mL (< 75 nmol/L) 25(OH)D, was 47% (Figure 1)[29].

Discussion

The interpretation and comparison of data from the studies identified in this review are limited by the varying methodologies, assay methods, geographical locations and population characteristics, as well as the differing thresholds of serum 25(OH)D used to define vitamin D inadequacy. However, the data suggest that there is a high rate of vitamin D inadequacy among postmenopausal women in Eastern Asia. The prevalence rates of 0–90% observed in this review for the proportion of Eastern Asian women with circulating 25(OH)D levels ≤6–35 ng/mL (≤15–87 nmol/L) are comparable with the 1.6–86% range [25(OH)D cut-off levels of ≤5–25 ng/mL or ≤12.5–62.5 nmol/L] found by Gaugris and colleagues in their systematic literature review[40]. They concluded that vitamin D inadequacy often affects a large proportion of postmenopausal women, particularly those with osteoporosis and a history of fracture[40].

Various expert groups have proposed a minimum serum 25(OH)D level of 30 ng/mL (≤ 75 nmol/L) for adequate nutrition[41–45], given that this threshold has been associated with maintenance of optimal bone mineral density, fracture prevention and reduced risk of some types of cancer. The large, global epidemiological study identified in this review applied this cut-off level as part of a standardized methodology to assess the prevalence of vitamin D inadequacy across all of the participating centres, including centres in four Eastern Asian countries for which prevalence rates of 47–92% (71% overall) for 25(OH)D levels of ≤ 30 ng/mL (≤ 75 nmol/L) were identified (Figure 1)[29]. However, high rates of vitamin D inadequacy were also observed among postmenopausal Eastern Asian women when lower 25(OH)D cut-off levels were applied.

Most of the body's vitamin D is produced in the skin in response to incident sunlight, with the remainder coming from dietary sources[46–48]. Skin synthesis of vitamin D is influenced by a variety of factors, including age (thinning of the skin reduces the efficiency of cutaneous synthesis and elderly people tend to spend more day time indoors) and factors that affect the amount of UV light reaching the skin (geographic latitude, smog levels, skin pigmentation and use of sunscreen and clothing). The elderly, and individuals whose exposure to sunlight is low, are highly dependent on dietary sources of vitamin D such as dairy food, eggs and fatty fish[46–48]. The most commonly reported factors responsible for inadequate levels of vitamin D in the studies identified in this review were age-related (aging populations in Japan, Taiwan and South Korea), geographical (marked seasonal changes in the northern latitudes of countries such as Japan, Taiwan, South Korea and China), cultural (complete covering of the skin is common in several countries e.g. Malaysia), cosmetic (e.g. high use of sunscreen and skin covering among women in Hong Kong, Malaysia and Taiwan) and dietary (diets low in vitamin D content are common in many countries e.g. China, Hong Kong, South Korea and Taiwan).

The modifiable nature of many of the risk factors for vitamin D inadequacy suggests that campaigns to raise awareness of the impact of lifestyle on vitamin D levels and the link between vitamin D inadequacy and osteoporosis and fracture could be effective in improving vitamin D status and bone health. The authors of the large multinational study suggested that a comprehensive campaign targeting modifiable risk factors and education about the importance of vitamin D, including the benefit of dietary supplementation, may be useful[23]. Additionally, various authors of studies conducted in Eastern Asia advocate the implementation of health education campaigns targeting patients with osteoporosis or at high risk of developing this condition[49–52]. A recent study of the effectiveness of an osteoporosis prevention campaign targeting women in Hong Kong, which was successful in stimulating increased consumption of vitamin D and calcium[49], concluded that educational programmes can favourably influence attitudes and behaviours toward osteoporosis intervention.

Dietary supplementation, via fortification of staple foodstuffs (i.e. dairy products) or individual supplementation, is a well established, cost-effective strategy for achievement and maintenance of optimal vitamin D levels[53]. Where food fortification is absent or insufficient, the most effective approach is individual supplementation with vitamin D or its derivatives by way of inexpensive over-the-counter oral formulations[54]. European and US national policies recommend individual supplementation with vitamin D in high-risk populations, such as postmenopausal women[42,45,53,55]. Oral vitamin D dosages of between 700 and 800 IU/day are recommended for fracture prevention[41,56,57], although maximum benefit requires the addition of an anti-resorptive agent such as a bisphosphonate[53,55].

Currently, nationwide strategies of vitamin D supplementation in Eastern Asian countries are the exception rather than the rule. The implementation of strategies in Eastern Asia similar to those used in Europe and the US requires consideration of potential ethnic differences in bone architecture and osteoporotic risk. Although some studies conducted in the US and South Africa indicate differences in serum 25(OH)D concentrations and bone density between black and white women[58,59], data comparing these factors in Asian and European women are extremely limited. One study found that although Asian women are generally shorter and lighter than their European counterparts, this does not appear to correspond to differences in bone mineral content[60]. Further research is required to determine whether ethnic differences in European versus Asian women influence their respective risk of vitamin D inadequacy.

Conclusions

Despite variations in the methodology, population characteristics, geographic locations and definitions of vitamin D status of epidemiological studies included in this review, the data suggest that a high proportion of postmenopausal women living in Eastern Asia have inadequate levels of vitamin D. Key drivers of vitamin D inadequacy in this population are dietary deficiency and restricted exposure or reactivity to sunlight due to cultural customs, lifestyle choices or aging. Useful strategies for the achievement and maintenance of optimal vitamin D levels in postmenopausal women in Eastern Asia include initiatives to increase awareness of the impact of vitamin D inadequacy on musculoskeletal health, education about the benefit of lifestyle modifications on vitamin D levels, and dietary vitamin D supplementation.

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