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Review

A glimpse of vitamin D status in Mainland China

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As an essential dietary micronutrient, vitamin D plays a pivotal role in promoting calcium absorption in the intestine and maintaining a healthy skeletal system throughout life. Beyond bone health, an emerging volume of scientific studies shows that vitamin D also may provide cardiovascular, metabolic, and immunologic benefits and reduce mortality. To our knowledge, in mainland China no national surveys have been conducted to date to depict the overall vitamin D status in the population. Therefore, the purpose of this contribution was to provide the best possible evaluation of vitamin D deficiency/insufficiency in China by reviewing publications that measured plasma/serum 25-hydroxyvitamin-D (25[OH]D) levels in various age groups and in different areas of China from January 2000 to June 2012. From these investigations conducted throughout the country and from newborns to adults to the elderly, it has been found that vitamin D deficiency/insufficiency is prevalent in the Chinese population in almost all age groups and areas if individuals are not taking vitamin D–fortified products/supplements or are lacking sufficient sunshine exposure. Some studies showed severe deficiency (25[OH]D <25 nmol/L) in Nanjing (north latitude 31) during the winter months and in Beijing (north latitude 40) in the fall. This unoptimistic situation represents a significant but modifiable public health risk that deserves greater attention and more efficient and timely management.

Introduction

Vitamin D is an essential dietary micronutrient because it plays a pivotal role in aiding intestinal absorption of calcium and phosphorus, therefore, exerting a favorable effect on bone mineralization and musculoskeletal health. Other than the classical effects of vitamin D on calcium and phosphorus metabolism and on bone health and muscle strength, an emerging volume of scientific studies also shows that vitamin D deficiency/insufficiency may increase the risks for developing non-skeletal disorders such as cardiovascular disease, type 2 diabetes, autoimmune disease, selected cancers, high blood pressure, depression, and overall mortality [1,2].

In Mainland China, there has, to our knowledge, been no systematic national survey to depict the landscape of vitamin D deficiency, insufficiency, and adequacy. However, research interests in the topic developed and continued to mount over the past decade(s), and as a result, circulating vitamin D status has been examined in various populations and regions.

The purpose of this contribution is to provide best possible overview from these studies that measured circulating 25-hydroxyvitamin-D (25[OH]D) levels in Mainland China. Serum or plasma 25(OH)D concentration is widely accepted as the best biomarker to define vitamin D status, because it reflects both the endogenous vitamin D photosynthesis by skin in response to sun exposure and vitamin D ingestion via digestive track from dietary sources [3]. To this end, peer-reviewed original English publications from January 2000 to November 2012, which examined 25(OH)D values, were retrieved from databases and analyzed. Studies were not included when the number of participants was less than 30 and when they had known overt vitamin D intake. A deficient vitamin D level is defined as being 25(OH)D <25 nmol/L; insufficient <50 nmol/L; desirable >75 nmol/L (as recommended by International Osteoporosis Foundation [IOF], the Endocrine Society, and many scientists in the field) [4]. Therefore, levels between 50 nmol/L and 75 nmol/L were defined as inadequate (although they are defined as adequate by the Institute of Medicine). These cut-off points are also in line with the recently published global vitamin D status map by the IOF [5] (http://www.iofbonehealth.org/facts-and-statistics/vitamin-d-studies-map).

Vitamin D status in the youth

As shown in Table 1 [6–12], vitamin D deficiency was phenomenal in the youth. There was no group with desirable

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Table 1
Vitamin D status in the youth

Publication	Age (yrs)	Number	Place	Latitude (north)	Season	D Use	Assay method	**25-OH-D (nmol/l)**	Deficiency (%)					
									<12.5	<25	<37.5	<50	<75	<80
Wang J. 2010	Newborn	77 (MF)	Chengdu	30	Sept	Unknown	Enzyme immunoassay	**41.0** ± **18.9**			44.2			96.1
Song S. 2012	Newborn	58 (MF)	Beijing	40	Apr-May	No	ELISA	**27.9** ± **1.6***		46.6		93.2	100	
Zhu Z. 2012	6-11	1440 (MF)	Hangzhou	30	All	Unknown	ELISA	**56.1** ± **19.9**		2.0		40.3	88.3	
	12-16	183 (MF)	Hangzhou	30	All	Unknown	ELISA	**52.1** ± **17.0**		3.3		46.4	89.6	
Du X. 2001	12.7	108 (F)	Beijing	40	Jan	Unknown	Competitive protein assay	**13.9** ± **9.6**	42.5					
					Sept-Oct	Unknown	Competitive protein assay	**30.2** ± **11.9**	5.1					
	13.0	57 (F)	Beijing	40	Jan	Unknown	Competitive protein assay	**12.7** ± **5.9**	49.6					
					Sept-Oct	Unknown	Competitive protein assay	**24.7** ± **10.6**	6.6					
	13.2	64 (F)	Beijing	40	Jan	Unknown	Competitive protein assay	**12.8** ± **6.7**	45.1					
					Sept-Oct	Unknown	Competitive protein assay	**23.8** ± **8.7**	9.2					
Foo L. 2009	15.0	301 (F)	Beijing	40	Mar-Apr	No	RIA	**34.0**		32.8	68.4	89.2		
Arguelles L. 2009	16.4	226 (FM)	Anqing	31	All	Unknown	HPLC	**45.0** ± **23.5**						90.3

M, male; F, female; All, the blood samples were collected in all seasons
The 25-OH-D values are expressed in mean ± SD (or mean ± SE when with *) or median, and are converted if not in nmol/l. Different deficiency/insufficiency cutoffs and rates were provided by investigators

25(OH)D levels and as many as 40% to 90% had blood 25(OH)D levels lower than 50 nmol/L. A study in Beijing showed even worse vitamin D status: More than 40% of school-aged girls had 25(OH)D levels below 12.5 nmol/L in January. This significant vitamin D deficiency remained in 5% to 9% of them even in September and October [9].

Poor vitamin D status was not seen in participants taking vitamin D–fortified products or supplementation (Table 2A) [8, 13], unequivocally suggesting that vitamin D supplementation improved 25(OH)D status. Additionally, exposure to sunshine, thus allowing individuals to receive ultraviolet B (UVB), in the summer months improved 25(OH)D status in the same children who were previously deficient (Table 2B) [14]. Consequently, clinical rickets declined from 41.6% to 17%.

Vitamin D status in adults

A larger percentage of adults had blood 25(OH)D levels below 50 nmol/L (Table 3) [6,7,15–27]. The best 25(OH)D levels (67.2 nmol/L) in adult groups were reported in Jinan [22]; whereas the worst (<25 nmol/L) was found in pregnant women in Nanjing and pregnant women with gestational diabetes mellitus in Beijing [15,20].

Surprisingly, in women of childbearing age, a lower 25(OH)D level also was found in lower latitude regions (29 nmol/L in Beijing versus 34 nmol/L in Hong Kong where the latitude is 22 north) [18].

Vitamin D status in the elderly

The elderly are fourfold less efficient in cutaneous vitamin D photosynthesis than youth [28,29] and are particularly vulnerable to bone fracture or mobility disorders. The 25(OH)D status was alarming in the fast-growing aging Chinese population (Table 4) [17,30–36]. There was no any study showing average 25(OH)D above 50 nmol/L. In two large-scale investigations in Beijing and Shanghai, as high as 70% to 90% of the participants had blood 25(OH)D levels below 50 nmol/L [30,35]. In 1460 elderly urban Shanghai residents, only 3.9% had plasma 25(OH)D levels >75 nmol/L [31]. Oral cholecalciferol (vitamin D_3) at 925 IU/d, raised serum 25(OH)D from 40 nmol/L to 50 nmol/L in 3 mo in 45 postmenopausal women [34].

Discussion

The data presented in this contribution are likely epitomic for the nation because the investigations were conducted in the east part of Hu's line (Fig. 1), which has been with <40% of the land and >90% of the population since 1930s [37]. In the global map of vitamin D deficiency/insufficiency [3,38], these data from China

Table 2
Vitamin D status can be improved in children

A. Effect of supplementation

Publication	Age (yrs)	Number	Place	Latitude (north)	Season	D Use	Assay method	25-OH-D (nmol/l)	Deficiency (%)		
									<25	<50	<75
Zhu Z. 2012	0–1	2116 (MF)	Hangzhou	30	All	Yes	ELISA	**98.7** ± **47.1**	0.4	5.4	33.6
	2–5	2269 (MF)	Hangzhou	30	All	Yes	ELISA	**69.6** ± **30.4**	1.1	21.9	68.6
Liang GY. 2011	0–10	76 (MF)	Nanjing	32	Nov-Mar	Yes	EIA	**80.5** ± **29.3**	1.3	10.5	
	0–10	66 (MF)	Nanjing	32	Nov-Mar	Yes	EIA	**65.7** ± **32.3***	16.7	30.8	

B. Effect of sunshine exposure

Publication	Age (month)	Number	Place	Latitude (north)/Elevation (meter)	Season	D Use	Assay method	**25-OH-D (nmol/l)**	Deficiency (%)		
									<12.5	<30	<50
Strand MA. 2009	18.2	177 (MF)	Yuci	37/797	Apr	Unknown	Radioimmunoassy	**34.5** ± **74.3**	33.5	65.3	84.3
	23.3	172 (MF)	Yuci	37/797	Sept	4.2%	Radioimmunoassy	**127.8** ± **143.5**	0	2.9	8.1

For footnote: please see Table 1
* With respiratory infection.

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Table 3
Vitamin D status in adults

Publication	Age (yrs)	Number	Place	Latitude (north)	Season	D Use	Assay method	**25-OH-D (nmol/l)**	Deficiency (%)			
									<25	<50	<75	<80
Jiang L. 2012	26.3	78 (F)	Nanjing	31	Winter	99 IU	ELISA	**22.6 ± 12.7**	65.8	96.1		
	27.7	78 (F)	Nanjing	31	Summer	117 IU	ELISA	**31.8 ± 9.2**	22.4	94.7		
Woo J. 2008	26.9	220 (F)	Beijing	40	Feb-May	No	Radio-immunoassay	**29**	40	94		
	27.9	*221 (F)*	*Hong Kong*	22	*Feb-May*	*No*	*Radio-immunoassay*	***34***[*]	18	92		
Shao H. 2012	26.8	130 (F)	Shanghai	31	Jul-Dec	No	Chemiluminescence	**30.2**[†]				
	27.3	139 (F)	Shanghai	31	Jul-Dec	No	Chemiluminescence	**29.7**				
Wang J. 2010	End preganacy	77 (F)	Chengdu	30	Sept	Unknown	Enzyme immunoassay	**36.0 ± 18.9**[†]				97.4
Tao M. 2012	28.1	1695 (F)	Shanghai	31	All	No	Chemiluminescence	**43.9 ± 28.6**[†]		69.0	91.0	
Yang B. 2012	29.4	41 (M)	Xi'an	34	All	Unknown	ELISA	**52.5 ± 15.9**				
	30.3	314 (M)	Xi'an	34	All	Unknown	ELISA	**53.3 ± 14.5**				
	30.5	195 (M)	Xi'an	34	All	Unknown	ELISA	**54.1 ± 14.3**				
Song S. 2012	29.9	70 (F)	Beijing	40	Apr-May	No	ELISA	**28.6 ± 1.4**[†]	54.3	90.2	100	
Yan L. 2000	30.9	48 (F)	Shenyang	42	Apr-May	No	Radio-immunoassay	**40.7 ± 14.1**	13.0			
	31.1	48 (M)	Shenyang	42	Mar-May	No	Radio-immunoassay	**31.4 ± 10.4**	29.0			
Wang O. 2012	31.0	200 (F)	Beijing	40	All	Unknown	ELISA	**25.9**[†]				
	32.0	200 (F)	Beijing	40	All	Unknown	ELISA	**22.4**[‡]	53.8	96.3		
Lu H. 2012	43.0	2588 (MF)	Shanghai	31	Feb-Mar	No	Chemiluminescence	52.2		30 (M) 46 (F)	84 (M) 89 (F)	
Yin X. 2012	49.4	601 (MF)	Jinan	37	Nov-Dec	No	RIA	**67.2 ± 25.3**		28.6	66	
Lin S. 2012	56.5	1101 (MF)	Linxian	36	Spring	No	Enzyme immunoassay	**31.7**				
Li L. 2012	Adults	1420 (MF)	Dali	25	Mar-May	No	RIA	**54.9**				
Ren C. 2012	Adults	197 (MF)	Guangzhou	23	All	No	ELISA	**48.9 ± 23.7**[§]		57.9	91.9	
Huang Y. 2012	Adults	49 (F)	Shanghai	31	Jan-Apr	No	Chemiluminescence	**29.4**				

Footnote: please see Table 1
The elevation in Dali is 2007 meters
[*] The data from Hong Kong were used for head-to-head comparison with Beijing.
[†] Pragnancy.
[‡] Pragnancy with gestational diabetes.
[§] Gastric cancer.

would stand for a sizable geographic area and the largest population.

Vitamin D deficiency/insufficiency in China might have been caused by multiple factors, some of which are unique and worthy of being recognized. First, with the rapid transformation from an agrarian to an industrialized society, the urban proportion of population increased from 33% in 2000 to 50% in 2013 (the fifth and sixth National Population Survey http://www.stats.gov.cn). Accordingly, the number of people engaged in an outdoor profession with sun exposure has dramatically decreased. Second, due to air pollution accompanied by industrialization and urbanization, people were discouraged from spending time outdoors and UVB was prevented from penetrating the atmosphere; Third, the preference for lighter skin color (fair skin) in the society remains unchanged, leading to popular use of hats, umbrellas, and sunscreens when outdoors. UVB radiation–related skin carcinomas also are increasingly a concern. Fourth, despite massive and successful improvements in macronutrient intakes in the Chinese population, micronutrient intake did improve in parallel [39]. In fact, natural food rich in vitamin D in the Chinese diet remain scarce, and food and beverages fortified with vitamin D are limited in the market.

Over the past several decades, the life span and life expectancy of the Chinese people has increased significantly, which brought the consequences of vitamin D deficiency, like osteoporosis and bone fracture, into greater prominence [40]. Accompanied by poor 25(OH)D status, a bone mineral density (BMD) survey with dual-energy X ray absorptiometry (DXA) in

Table 4
Vitamin D status in the elderly

Publication	Age (yrs)	Number	Place	Latitude (north)	Season	D Use	Assay method	25-OH-D (nmol/l)	Deficiency (%)		
									<25	<50	<75
Lu L. 2009	50-70	3262 (MF)	Shanghai Beijing	31 40	Apr-Jun	Unknown	Radio-immunoassay	**40.4**		69.2	
Dorjgochoo T. 2012	61	1460 (MF)	Shanghai	31	All	Unknown	chemiluminescence	**34.7**			96.1
Kruger M. 2012	61.5	32 (F)	Beijing	40	Feb-May	No	Chemiluminescence	**33.1 ± 15.5**			
	62.7	31 (F)	Beijing	40	Feb-May	No	Chemiluminescence	**29.3 ± 12.0**			
Zhou X. 2012	62.1	181 (MF)	Beijing	40	All	No	ELISA	**35.8 ± 12.4**	20.4	86.1	100
	63.6	193 (MF)	Beijing	40	All	No	ELISA	**32.1 ± 10.8**[*]	21.2	94.3	100
Zhang H. 2012	63.8	100 (F)	Shanghai	31	Dec-Mar	<600IU	Chemiluminescence	**42.0 ± 13.5**			
Zhao J. 2011	64.1	1724 (F)	Beijing	40	Unknown	Unknown	Chemiluminescence	**33.0 ± 13.5**		89.7	99.4
Yan L. 2003	65.2	110 (F)	Shenyang	42	Feb-Apr	14.5%	Radio-immunoassay	**30.9 ± 13.5**	39.1		
	67.9	108 (M)	Shenyang	42	Feb-Apr	9.3%	Radio-immunoassay	**27.1 ± 11.5**	52.8		
Yan L. 2000	66.9	48 (F)	Shenyang	42	Apr-May	No	Radio-immunoassay	**42.9 ± 21.2**	15.0		
	68.9	50 (M)	Shenyang	42	Mar-May	No	Radio-immunoassay	**28.4 ± 12.5**	48.0		

Footnote: please see Table 1
[*] With COPD.

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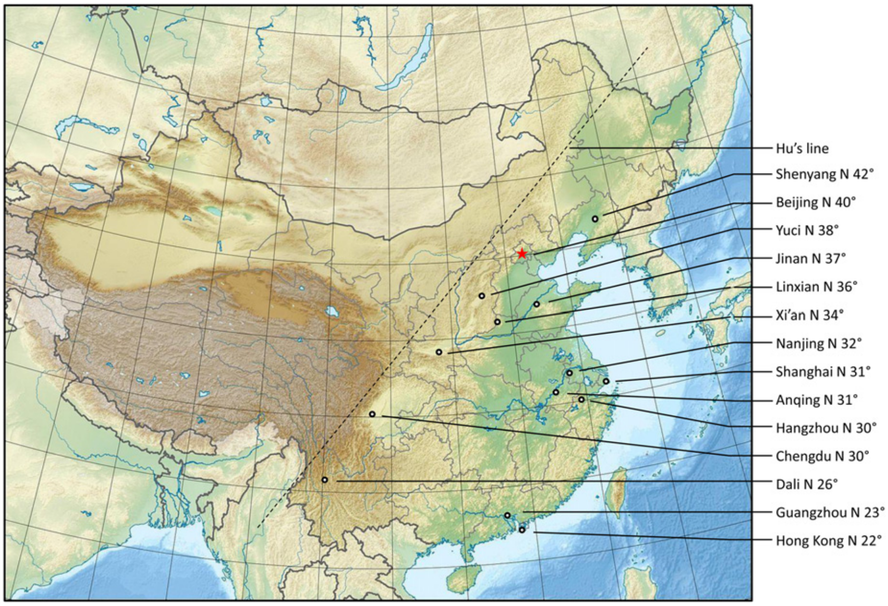

Fig. 1. Distribution of studies. In some places like Beijing and Shanghai, multiple studies were conducted. The original blank map is from http://en.wikipedia.org/wiki/File:China_edcp_relief_location_map.jpg#file. The map is licensed under Creative Commons ShareAlike 3.0 http://creativecommons.org/licenses/by-sa/3.0/deed.en.

10 Chinese cities estimated that the proportion of osteoporosis in men and women over age 50 y was 10.4% and 31.2%, respectively [41]. Furthermore, the incidence of hip fracture in Beijing in the period 2002 to 2006 escaladed much more rapidly compared with 1990 to 1992 [42]. Vitamin D deficiency increases the risk for both osteoporosis and falls [43,44], which are the two major risks for bone fracture.

In summary, from published investigations in Mainland China since the year 2000, vitamin D deficiency/insufficiency was found to be widely prevalent, which constitutes a significant but modifiable public health risk that deserves greater awareness and more efficient and timely management. To attain a desirable vitamin D status at the population level, it requires multiple approaches (e.g., promotion of a healthy lifestyle, implementation of recommended daily intake, development of voluntary and mandatory fortification programs, and regulation establishment and reinforcement).

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