CMJ Clinical Medicine

Research Article

Comparison of Lumbar and Hip Bone Mass in the Postmenopausal Women at Different Ages

Tao Shi*, Tao Zhang, Donghui Teng, Wanli Jing, Qiang Zhou and Zhongyu Gao

Department of Orthopedics, Tianjin First Central Hospital, School of Medicine, Nankai University, China

Abstract

This article aimed to determinate the bone mass characteristics of lumbar and hip in postmenopausal women at the different ages. The medical records of postmenopausal women from January 2011 to September 2019 were retrospectively collected. The demography and results of Dual-Energy X-ray Absorptiometry (DXA) on lumbar and hip were collected. The Body Mass Index (BMI) was calculated. The Bone Mineral Content (BMC) and Bone Mineral Density (BMD) were collected and compared in different age groups and sites. A total of 13191 patients were enrolled from January 2011 to September 2019. There were significant differences on BMC and BMD of L2, L3, L4 vertebrae body, FN and FT between the 4 age groups (P<0.01). There were significant differences on BMI between the 4 age groups (P<0.01). At the same age group there were significant differences on the BMC and BMD between the different vertebrae bodies and different sites of hip (P<0.01). There were significant differences on the mean age, BMI, BMC, area and BMD of vertebrae body and hip between the three groups that were divided according to T score of FN (P<0.00) and FT (P<0.00). In postmenopausal women, lumbar bone mass increases with the increase of weight and changes with age in an inverted parabola pattern. The bone mass of FT was more than that of FN, and the bone mass of the hip decreased gradually with the increase of age. The bone mass of the same lumbar spine decreased with the decrease of T score of FN and FT.

Keywords: Bone mass; Postmenopausal women; Hip; Vertebral body; Characteristics

Introduction

Osteoporosis is a silent killer for human health and major public health concern. In 2006 there were about 70 million osteoporotic patients and over 200 million patients with osteopenia in China [1]. In 2015 there were about 2.69 million cases on osteoporotic fracture in Chinese population [2]. Osteoporosis mainly results in vertebral compression fracture and hip fracture that include Femoral Neck (FN) and Femoral Trochanter (FT) fractures, secondly surgical neck fractures of the humerus and distal radius fractures. In China the prevalence of vertebral fracture in postmenopausal women raised from 13.4% at ages 50-59 years to 58.1% at age >80 years [3]. There were about 1.6 million hip fractures occurred worldwide in 2000, but this number is expected to increase to 6.3 million by 2050 [4]. The hip fractures in China are more prevalent in Africa and South America and less prevalent in northern Europe and the USA [5].

According to the research, Asians have a lower bone mass than Caucasians and Afro-Caribbeans and the peak incidence of osteoporosis is believed to occur 10-20 years earlier in Indians than in the Western population [6-10]. There were some reports on vertebral and hip fractures in postmenopausal Chinese women [3,11,12]. But there was little study on bone mass about postmenopausal Chinese women, especially on characteristics of different age groups and sites. This study aims to review the bone mass of postmenopausal women in the single center from 2011 to 2019 in a municipality city of north China and analyze characteristics of bone mass in the different age groups and sites.

Citation: Shi T, Zhang T, Teng D, Jing W, Zhou Q, Gao Z. Comparison of Lumbar and Hip Bone Mass in the Postmenopausal Women at Different Ages. CMJ Clin Med. 2024; 1(1): 1001.

Publisher Name: MedClinics Journals

Received: Mar 11, 2024; **Accepted:** Apr 19, 2024; **Published:** Apr 24, 2024

***Corresponding author:** Tao Shi, Department of Orthopedics, Tianjin First Central Hospital, School of Medicine, Nankai University, No. 24, Fukang Road, Nankai District, Tianjin 300192, China, E-mail: shitaostone@163.com

Materials and Methods

Participants

The patients' Dual-Energy X-Ray Absorptiometry (DXA) results were reviewed from 2011 to 2019 in our hospital. Those patients' medical records were reviewed. The inclusive criteria: 1) age>50 years old; 2) natural menopause for more than 2 years; 3) low back pain or general joint pain; 4) spinal deformation; vertebral body compression or FN or FT fracture(s) caused by tiny force; 5) DXA was used to assess the osteoporosis. The exclusive criteria: 1) osteoporosis secondary to various metabolic diseases, such as thyroid or parathyroid disease, and other endocrine diseases; 2) long-term bedridden patient; 3) accept the anti-osteoporosis treatment; 4) osteoporosis caused by any other diseases; 4) no DXA results.

Grouping

The patients were grouped according to age. Each group was 10 years old from >50 years. According to the T score of FN and FT, the patients were divided into three groups: group A was T score>-1, group B was >-1 T score>-2.5 and group C was T score <-2.5. According to the definition, T score>-1 was normal, -1>T score>-2.5 was osteopenia and T score <-2.5 was osteoporosis.

DXA assessment

The DXA results were export from computer that was match with test machine. The Bone Mineral Content (BMC), area and Bone Mineral Density (BMD) of spine were collected. The BMC, area, BMD and T score of FN and FT were collected. The BMC, BMD and T score were collected. There were some DXA results that were not displayed in the export data. The spine included L2, L3 and L4 vertebrae body, and the hip included FT, FN and Ward's triangle.

Statistical analysis

Descriptive statistics are expressed as mean ± SD. Variables between the different groups and site were compared using ANOVA test. A P value of <0.05 was considered statistically significant. Statistical analyses were performed using SPSS software (version 11.0, SPSS Inc., Chicago, IL, USA).

Results and Discussion

Distribution of patients

There were 13191 patients enrolled in this study. According to age the 61-70 age group accounted for 36.67% and 81-90 for 7.51% (Figure 1). Figure 2 displayed the distribution of patients in the different years. The number of patients with osteopenia was 7153 and accounted for 54.23%, osteoporosis was 1430 and accounted for 10.84% but normal was 4608 and accounted for 34.93% taking the T score of FN as standard. However, taking the T score of FT as standard, osteopenia was 5674 and accounted for 43.01%, osteoporosis was 2891 and accounted for 21.92% and normal was 4626 and accounted for 35.07%.

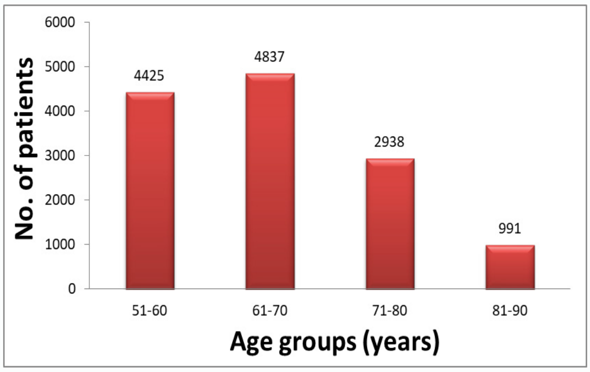

Figure 1: The distributions of patients in the different age groups.

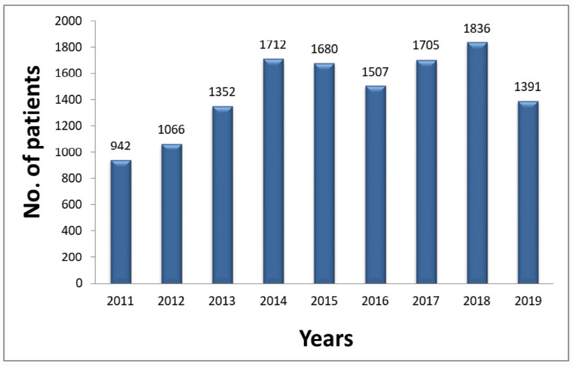

Figure 2: The distributions of patients in the different years.

Vertebrae body and hip bone mass analysis

There were significant differences on BMC and BMD of L2, L3, L4 vertebrae body, FN and FT between the 4 age groups (P<0.01, Table 1). Also, there were significant differences on BMI between the 4 age groups (P<0.01, Table 1). At the same age group there were significant differences on the BMC and BMD between the different vertebrae bodies and different sites of hip (P<0.01, Table 2).

During the 4 age groups the highest BMC of vertebrae body was 51-60 ages group, the lowest was 71-80. The BMC of L4 vertebrae body was highest followed by L3 and L2 in all the 4 age groups. The highest BMD of vertebrae body was the same as BMC. During the 4 age groups the highest BMC of hip was 51-60 ages group and the lowest was 81-90. The BMC of FT was higher than FN in all 4 age groups. The highest BMD of hip was the same as BMC. In all the 4 age groups the BMC of vertebrae body was higher than hip. The BMC and BMD of L4 vertebrae body was the highest and the Ward's triangle was the lowest. Figure 3 and 4 displayed the trends of BMC and BMD in different age groups and sites of vertebrae body and hip.

Analysis of bone mass between the groups according to FN and FT

There were significant differences on the mean age, BMI, BMC, area and BMD of vertebrae body and hip between the three groups that were divided according to T score of FN (P<0.00, Table 3) and FT (P<0.00, Table 4).

In the three groups divided according to T score of FN the BMC and BMD of group A were the highest and the group B was the lowest. However, in the three groups divided according to T score of FT the BMC and BMD of group A were the highest and the group C was the lowest.

Discussion

Postmenopausal women osteoporosis is a health threat for the female. Chinese constitutes one-fifth of the world's population and an even greater proportion of the older population, especially postmenopausal women [13]. There were some reports about epidemiology of osteoporosis in different countries that showed the unique characteristics of osteoporosis in different region and race [14-17]. It is well known that China is a vast country and the climate, diet and habit are great different in different regions of the country. However, there were some studies on prevalence of osteoporosis about Chinese that included the cross-sectional study in the multicenter and regional studies with small sample size [3,18,19], there was few report on bone mass characteristics of large sample of postmenopausal women in the local area of China. This research was about bone mass characteristics of 13225 postmenopausal women in municipality city of north China.

In this study the participants were age >50 years old and natural menopause for more than 2 years women. As we knew the postmenopausal women suffered bone mass loss due to the estrogen deficiency post-menopause. This bone mass loss significantly aggravated with the increase of menopause time. But there was a research on osteoporosis that showed low BMD is not a disorder confined to postmenopausal women alone and widely prevalent in women above 40 years of age [20]. Also, there was a high prevalence of osteoporosis and fracture in China; 5.0% of men and 20.6% of women aged 40 years or older had osteoporosis, and 10.5% of men and 9.7% of women aged 40 years or older had vertebral fracture [17]. According to the above studies postmenopausal bone mass loss may be continuation of premenopausal osteoporosis.

In this study the bone mass was highest in the L4 vertebrae body followed by L3 and L2 at any age group, and FT>FN>Ward's triangle at the hip. BMD of vertebrae body was the same as BMC: L4>L3>L2, but at the hip the BMD was FN>FT>Ward's triangle at any age group. There was a research that displayed T-score discordance between spine and total hip measurement sites [21]. Another study showed that the weight-bearing bones have higher

Table 1: Analysis of DXA results on different sites of lumbar and hip between the five age groups (n=13191).

	Age groups				
	51-60 (n=4425)	61-70 (n=4837)	71-80 (n=2938)	81-90 (n=991)	P
L2 Vertebrae body					
BMC (g)	12.84 ± 3.32	12.41 ± 3.70	12.32 ± 4.30	12.81 ± 4.78	<0.01
BMD (g/cm²)	0.91 ± 0.19	0.86 ± 0.20	0.85 ± 0.23	0.87 ± 0.24	<0.01
L3 Vertebrae body					
BMC (g)	14.53 ± 3.70	13.85 ± 4.09	13.81 ± 4.69	14.34 ± 5.57	<0.01
BMD (g/cm²)	0.95 ± 0.20	0.90 ± 0.21	0.89 ± 0.24	0.91 ± 0.26	<0.01
L4 Vertebrae body					
BMC (g)	16.09 ± 4.36	15.57 ± 4.68	15.37 ± 5.38	16.02 ± 6.01	<0.01
BMD (g/cm²)	0.97 ± 0.20	0.93 ± 0.22	0.92 ± 0.22	0.94 ± 0.27	<0.01
FN					
BMC (g)	3.67 ± 0.90	3.43 ± 0.95	3.18 ± 0.94	3.10 ± 0.97	<0.01
BMD (g/cm²)	0.76 ± 0.14	0.71 ± 0.14	0.65 ± 0.14	0.62 ± 0.14	<0.01
FT					
BMC (g)	7.21 ± 2.15	6.82 ± 2.25	6.36 ± 2.32	6.04 ± 2.46	<0.01
BMD (g/cm²)	0.63 ± 0.12	0.59 ± 0.13	0.55 ± 0.13	0.52 ± 0.14	<0.01
Ward's Triangle					
BMD (g/cm²)	0.54 ± 0.14	0.48 ± 0.13	0.43 ± 0.14	0.41 ± 0.12	<0.01
BMI	24.32 ± 3.96	24.62 ± 5.01	24.15 ± 4.06	23.28 ± 4.09	<0.01

Table 2: Analysis of DXA results on different sites of lumbar and hip at the same group (n=13191).

	Age groups			
	51-60 (n=4425)	61-70 (n=4837)	71-80 (n=2938)	81-90 (n=991)
BMC (g)				
L2 Vertebrae body	12.84 ± 3.32	12.32 ± 3.70	12.41 ± 4.30	12.81 ± 4.78
L3 Vertebrae body	14.53 ± 3.70	13.85 ± 4.09	13.81 ± 4.69	14.34 ± 5.57
L4 Vertebrae body	16.09 ± 4.36	15.37 ± 4.68	15.57 ± 5.38	16.02 ± 6.01
P	<0.01	<0.01	<0.01	<0.01
FN	3.67 ± 0.90	3.43 ± 0.95	3.18 ± 0.94	3.10 ± 0.97
FT	7.21 ± 2.15	6.82 ± 2.25	6.36 ± 2.32	6.04 ± 2.46
P	<0.01	<0.01	<0.01	<0.01
BMD (g/cm²)				
L2 Vertebrae body	0.91 ± 0.19	0.86 ± 0.20	0.85 ± 0.23	0.87 ± 0.24
L3 Vertebrae body	0.95 ± 0.20	0.90 ± 0.21	0.89 ± 0.24	0.91 ± 0.26
L4 Vertebrae body	0.97 ± 0.20	0.92 ± 0.22	0.93 ± 0.22	0.94 ± 0.27
P	<0.01	<0.01	<0.01	<0.01
FN	0.76 ± 0.14	0.71 ± 0.14	0.65 ± 0.14	0.62 ± 0.14
FT	0.63 ± 0.12	0.59 ± 0.13	0.55 ± 0.13	0.52 ± 0.14
Ward's Triangle	0.54 ± 0.14	0.48 ± 0.13	0.43 ± 0.14	0.41 ± 0.12
P	<0.01	<0.01	<0.01	<0.01

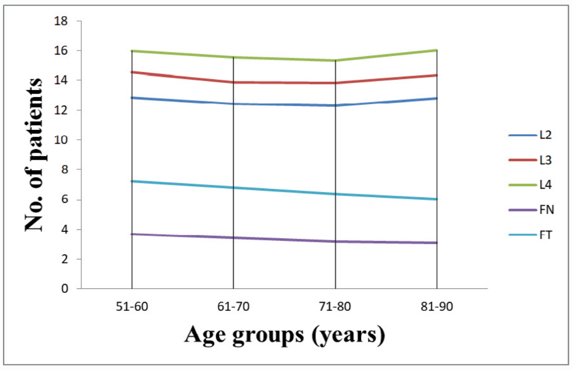

Figure 3: The BMC of patients in the different vertebrae body and sites of hip.

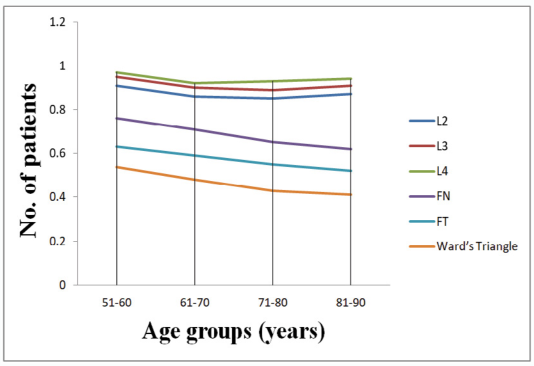

Figure 4: The BMD of patients in the different vertebrae body and sites of hip.

BMD [22]. According to the above two studies the L4 vertebrae body was weight-bearing bone with respect to L2 and FN was weight-bearing bone relative to FT. As to the discordance between BMC and BMD at the different sites of hip, that may be due to the different area between the FN and FT. As is well-known bone mass at the Ward's triangle is less than FN and FT even in healthy people. The reason is that bone grows along with stress and is stronger in the load-bearing position to support the body's weight.

In this study the bone mass decreased with age increase at the spine and hip, but the 76-80 ages group was lowest at the spine and 81-85 ages group at the hip. According to the bone mass loss due to estrogen production decreases with age increase, postmenopausal women bone mass continued to decrease. But

Table 3: Analysis of DXA results on different groups according to T score of FN (n=13191).

	Group A (n=4608)	Group B (n=7153)	Group C (n=1430)	P
Mean age (years)	61.42 ± 7.64	67.36 ± 8.81	70.67 ± 9.76	<0.00
BMI	25.46 ± 3.91	23.93 ± 4.64	22.51 ± 3.83	<0.00
BMC (g)				
L2 Vertebrae body	13.87 ± 3.83	11.68 ± 3.45	12.68 ± 4.33	<0.00
L3 Vertebrae body	15.73 ± 4.14	13.09 ± 3.83	13.96 ± 4.92	<0.00
L4 Vertebrae body	17.47 ± 4.95	14.58 ± 4.36	15.35 ± 5.23	<0.00
BMD (g/cm^2)				
L2 Vertebrae body	0.98 ± 0.21	0.82 ± 0.18	0.82 ± 0.21	<0.00
L3 Vertebrae body	1.03 ± 0.22	0.86 ± 0.19	0.84 ± 0.22	<0.00
L4 Vertebrae body	1.05 ± 0.22	0.88 ± 0.20	0.86 ± 0.23	<0.00

Table 4: Analysis of DXA results on different groups according to T score of FT (n=13191).

	Group A (n=4626)	Group B (n=5674)	Group C (n=2891)	P
Mean age (years)	62.69 ± 8.41	65.62 ± 8.62	70.42 ± 9.19	<0.00
BMI	25.60 ± 3.89	24.18 ± 4.66	22.51 ± 4.02	<0.00
BMC (g)				
L2 Vertebrae body	14.83 ± 4.17	11.88 ± 2.95	10.24 ± 2.71	<0.00
L3 Vertebrae body	16.77 ± 4.47	13.37 ± 3.27	11.30 ± 3.02	<0.00
L4 Vertebrae body	18.55 ± 5.07	14.90 ± 3.97	12.59 ± 3.45	<0.00
BMD (g/cm^2)				
L2 Vertebrae body	1.02 ± 0.21	0.83 ± 0.16	0.72 ± 0.15	<0.00
L3 Vertebrae body	1.07 ± 0.22	0.87 ± 0.16	0.75 ± 0.16	<0.00
L4 Vertebrae body	1.09 ± 0.22	0.90 ± 0.17	0.77 ± 0.17	<0.00

this situation was not reality. In this study the bone mass loss of spine was peak at the 76-80 years old and hip at the 81-86 years old. This may be association with endocrine change, diet, physiologic and pathologic patient factors.

In this study the bone mass at the hip was significantly lower than at the spine at the same age group. There were some studies that demonstrated the periosteal apposition caused expansion of the FN and FT with increasing age [23-29]. Periosteal apposition partly compensates for a decrease of bone strength caused by a decrease in BMC and cortical thickness. The increasing periosteal apposition with increasing age may be an important mechanism to slow the decrease of fracture resistance [30]. But in women, periosteal apposition ceases after menopause [31]. This periosteal apposition ceases cease and decrease of estrogen may be the reason of bone mass loss at the hip higher than spine.

The patients were divided into three groups according to T score of FN and FT. Between the three groups according to T score of FN the bone mass of the normal group was highest, but the osteopenia group was lowest at the spine sites and the order was L4>L3>L2 at the same group. The results of bone mass at the hip were the same as spine and the order was FT>FN>Ward's triangle at the same group. Between the three groups according to T score of FT the bone mass of the normal group was highest and the osteoporosis group was lowest at the spine sites and the order was L4>L3>L2 at the same group. The results of bone mass at the hip were the same as spine and the order was FT>FN>Ward's triangle at the same group. Those results again showed that weight-bearing bone had a higher bone mass [21]. The bone mass at the FT was higher than FN, but the area of FT was larger than FN, BMD of FT was still higher than FN. The difference of area size at the different skeletal sites may be association with age [32-37] and the amount of periosteal apposition varied with skeletal site, age and sex [36,38-40]. The BMC and BMD of Ward's triangle were the lowest at any group.

Conclusion

This study showed that bone mass decreased with increasing age, but the bottoms of spine and hip were different. The bone mass of spine was higher than hip at the same age group. The bone mass at the weight-bearing sites was higher.

References

1. Chinese health promotion foundation editorial board of Chinese White Papers of osteoporosis. Chinese white papers of osteoporosis. Chin J Health Manag. 2009;3:148-54.

2. Si L, Winzenberg TM, Jiang Q, Chen M, Palmer AJ. Projection of osteoporosis-related fractures and costs in China: 2010-2050. Osteoporos Int. 2015;26(7):1929-37.

3. Cui L, Chen L, Xia W, Jiang Y, Cui L, Huang W, et al. Vertebral fracture in postmenopausal Chinese women: a population-based study. Osteoporos Int. 2017;28(9):2583-90.

4. Cooper C, Cole ZA, Holroyd CR, Earl SC, Harvey NC, Dennison EM, et al. Secular trends in the incidence of hip and other osteoporotic fractures. Osteoporos Int. 2011;22(5):1277-88.

5. Dhanwal DK, Dennison EM, Harvey NK, Cooper C. Epidemiology of hip fracture: Worldwide geographic variation. Indian J Orthop. 2011;45:15-22.

6. Mithal A. Bone mineral health of Indians. Natl Med J India. 2003;16(6):291e4.

7. Marwaha RK, Tandon N, Kaur P, Sastry A, Bhadra K, Narang A, et al. Establishment of age-specified bone mineral density reference range for Indian females using dual-energy X-ray absorptiometry. J Clin Densitom. 2012;15(2):241-9.

8. Population based reference standards of peak bone mineral density of Indian males and females e an ICMR multi-centre task force study. Published by Director General, New Delhi: ICMR; 2010;1-24.

9. Paul T, Mruthyunjaya M, Shyamasunder A, Naik D, Rajaratnam S, Thomas N, et al. The diagnosis of osteoporosis among subjects of southern Indian origin above 50 years of age: the impact of the Indian council of medical research versus Caucasian bone mineral density reference standards. Indian J Endocrinol Metab. 2013;31:27.

10. Mittal S, Kumar A, Gupta RK, Kapoor S, Gulati P, Shukla DK. Comparison of bone mineral density and its variables between premenopausal and postmenopausal women. J Obstet Gynaecol India. 2011;61:200-4.

11. Cui L, He T, Jiang Y, Li M, Wang O, Jiajue R, et al. Predicting the intervention threshold for initiating osteoporosis treatment among postmenopausal women in China: a cost-effectiveness analysis based on real-world data. Osteoporosis International. 2020;31:307-16.

12. Su S, Wang L, Liu X, Yang M, Yi C, Liu Y, et al. Lack of periosteal apposition in the head and neck of femur after menopause in Chinese women with high risk for hip fractures-A cross-sectional study with QCT. Bone. 2020;139:115545.

13. National Bureau of Statistics of People's Republic of China. 2018 Statistical bulletin of national economic and social development. 2019.

14. Baccaro LF, Conde DM, Costa-Paiva L, Pinto-Neto AM. The epidemiology and management of postmenopausal osteoporosis: a viewpoint from Brazil. Clin Interv Aging. 2015;10:583-91.

15. Cipriani C, Pepe J, Bertoldo F, Bianchi G, Cantatore FP, Corrado A, et al. The epidemiology of osteoporosis in Italian postmenopausal women according to the National Bone Health Alliance (NBHA) diagnostic criteria: a multicenter cohort study. J Endocrinol Invest. 2018;41(4):431-8.

16. Chen KK, Wee SL, Pang BWJ, Lau LK, Jabbar KA, Seah WT, et al. Bone mineral density reference values in Singaporean adults and comparisons for osteoporosis establishment-The Yishun Study. BMC Musculoskeletal Disord. 2020;21(1):633.

17. Wang L, Yu W, Yin X, Cui L, Tang S, Jiang N, et al. Prevalence of Osteoporosis and Fracture in China: The China Osteoporosis Prevalence Study. JAMA Netw Open. 2021;4(8):e2121106.

18. Li N, Ou P, Zhu H, Yang D, Zheng P. Prevalence rate of osteoporosis in the mid-aged and elderly in selected parts of China. Chin Med J (Engl). 2002;115(5):773-5.

19. Ling X, Cummings SR, Mingwei Q, Xihe Z, Xioashu C, Nevitt M, et al. Vertebral fractures in Beijing, China: the Beijing Osteoporosis Project. J Bone Miner Res. 2000;15(10):2019-2025.

20. Chawla J, Sharma N, Arora D, Arora M, Shukla L. Bone densitometry status and its associated factors in peri and postmenopausal females: A cross sectional study from a tertiary care centre in India. Taiwan J Obstet Gynecol. 2018;57(1):100-5.

21. Younes M, Hammouda SB, Jguirim M, Younes K, Zrour S, Béjia I, et al. Discordance between spine and hip Bone Mineral Density measurement using DXAin osteoporosis diagnosis: Prevalence and risk factors. Tunis Med. 2014;92(1):1-5.

22. Espallargues M, Sampietro-Colom L, Estrada MD, Solà M, del Rio L, Setoain J, et al. Identifying Bone-Mass-Related Risk Factors for Fracture to Guide Bone Densitometry Measurements: A Systematic Review of the Literature. Osteoporos Int. 2001;12(10):811-22.

23. Nicks KM, Amin S, Melton LJ 3rd, Atkinson EJ, McCready LK, Riggs BL, et al. Three-dimensional structural analysis of the proximal femur in an age-stratified sample of women. Bone. 2013;55(1):179-88.

24. Poole KES, Mayhew PM, Rose CM, Brown JK, Bearcroft PJ, Loveridge N, et al. Changing structure of the femoral neck across the adult female lifespan. J Bone Miner Res. 2010;25(3):482-91.

25. Riggs BL, Iii LJM 3rd, Robb RA, Camp JJ, Atkinson EJ, Peterson JM, et al. Population-based study of age and sex differences in bone volumetric density, size, geometry, and structure at different skeletal sites. J Bone Miner Res. 2004;19(12):1945-54.

26. Johannesdottir F, Aspelund T, Reeve J, Poole KE, Sigurdsson S, Harris TB, et al. Similarities and differences between sexes in regional loss of cortical and trabecular bone in the mid-femoral neck:the AGES-Reykjavik longitudinal study. J Bone Miner Res. 2013;28(10):2165-76.

27. Khoo BCC, Brown JK, Prince RL. Reconsideration of the effects of age on proximal femur structure: implications for joint replacement and hip fracture. PLoS One. 2016;11(10):e0164949.

28. Jepsen KJ, Kozminski A, Bigelow EM, Schlecht SH, Goulet RW, Harlow SD, et al. Femoral neck external size but not a BMD predicts structural and mass changes for women transitioning through menopause. J Bone Miner Res. 2017;32(6):1218-28.

29. Wang L, Cheng XG, Su YB, Brown K, Xu L, Li K,. Sex-related variations in cortical and trabecular bone of the femoral neck in an elderly Chinese population. Osteoporos Int. 2017;28(8):2391-9.

30. Seeman E. Periosteal bone formation--a neglected determinant of bone strength. N Engl J Med. 2003;349(4):320-3.

31. Szulc P, Seeman E, Duboeuf F, Sornay-Rendu E, Delmas PD. Bone fragility: failure of periosteal apposition to compensate for increased endocortical resorption in postmenopausal women. J Bone Miner Res. 2006;21(12):1856-63.

32. Beck TJ, Looker AC, Ruff CB, Sievanen H, Wahner HW. Structural trends in the aging femoral neck and proximal shaft:analysis of the third national health and nutrition examination survey dual-energy X-ray absorptiometry data. J Bone Miner Res. 2006;15(12):2297-304.

33. Jepsen KJ, Andarawis-Puri N. The amount of periosteal apposition required to maintain bone strength during aging depends on adult bone morphology and tissue modulus degradation rate. J Bone Miner Res. 2012;27(9):1916-26.

34. Szulc P, Delmas PD. Bone loss in elderly men:increased endosteal bone loss and stable periosteal apposition. The prospective MINOS study. Osteoporos Int. 2007;18(4):495-503.

35. Khoo BCC, Brown K, Lewis JR, Perilli E, Prince RL. Ageing effects on 3-dimensional femoral neck cross-sectional asymmetry:implications for age-related bone fragility in falling. J Clin Densitom. 2019;22(2):153-61.

36. Kaptoge S, Dalzell N, Loveridge N, Beck TJ, Khaw KT, Reeve J. Effects of gender, anthropometric variables, and aging on the evolution of hip strength in men and women aged over 65. Bone. 2003;32(5):561-70.

37. Ahlborg HG, Johnell O, Turner CH, Rannevik G, Karlsson MK. Bone loss and bone size after menopause. N Engl J Med. 2003;49(4):327-34.

38. Lazenby RA. Continuing periosteal apposition. I:documentation, hypotheses, and interpretation. Am J Phys. Anthropol. 1990;82(4):451-72.

39. Sigurdsson G, Aspelund T, Chang M, Jonsdottir B, Sigurdsson S, Eiriksdottir G, et al. Increasing sex difference in bone strength in old age:the age, gene/environment susceptibility-Reykjavik study (AGES-REYKJAVIK). Bone. 2006;39(3):644-51.

40. Heaney RP, Barger-Lux, Davies KM, Ryan RA, Johnson ML, Gong G. Bone dimensional change with age:interactions of genetic, hormonal, and body size variables. Osteoporos Int. 1997;7(5):426-31.