The Optimal Cut-Points for Weight and Non-Weight Quantitative Ultrasound of the Calcaneus to Screen Osteoporosis in Postmenopausal Women

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Objective: *To determine the optimal cut-off point of quantitative ultrasound (QUS) of the calcaneus, and optimized position for QUS of the calcaneus, between non-weight (sitting) and weight (standing) position, to screen osteoporosis in postmenopausal women.*

Material and Method: *A cross-sectional study of postmenopausal women aged 65 years or older who came for bone mineral density (BMD) evaluation at the menopause unit, Department of Obstetrics and Gynecology, Ramathibodi Hospital between April 2013 and October 2015. Bone tissue was measured by using QUS of the calcaneus in the standard sitting (non-weight position) and in standing (weight position) consecutively of non-dominant calcaneus to compared with BMD that measured by dual energy X-ray absorptiometry (DXA) of lumbar spine and hip within the same visit of QUS measurement. The area under Receiver Operating Characteristic (ROC) curve and optimal of diagnostic properties to diagnosed osteoporosis were analyzed by sensitivity, specificity, positive and negative likelihood ratio (LR+/-).*

Results: *One hundred sixty one postmenopausal women were enrolled, median age was 70 (65, 94) years old, median time since menopause was 22 (10, 55) years. Ten point five percent of subjects had history of osteoporotic fracture at wrist. The prevalence of osteoporosis was 23% at lumbar spine and 30% at femoral neck respectively. Area under ROC curve for diagnosed osteoporosis was 0.73 in the non-weight QUS of the calcaneus and correlated well with using DXA at neck of femur (gold standard). However, the weight or standing position did not improve the diagnostic power of QUS of the calcaneus. The optimal cut-point value of QUS of the calcaneus to screen osteoporosis at stiffness index was determined by T-score of ≤ -2.6 with 81.42%, 45.83%, 1.5, and 0.41 for the sensitivity, specificity, LR+/- respectively.*

Conclusion: *QUS of the calcaneus was acceptable and promising to be alternative tool for screening osteoporosis in postmenopausal woman age older than 65 years by the optimal cut-point of stiffness index T-score at ≤ -2.6 measured in standard position or non-weight method.*

Keywords: *QUS, DXA, Calcaneus, Ultrasound, Osteoporosis, Screening, Weight, Non-weight*

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Osteoporosis is recognized as abnormal pathology of skeleton disorder which characterized by compromised bone strength, primarily reflects the integration of bone density and bone quality with consequence bone fragility and susceptibility to fracture[1]. Most of osteoporosis is usually asymptomatic but can lead to osteoporotic fracture. The common sites of fracture are spine, hip, and forearm. These burdens lead to significant physical morbidity associate with later increased mortality. These consequences are from immobilization or being bed ridden. Recent report shows osteoporotic hip fracture is the greatest morbidity among all osteoporotic fractures and results in the highest direct costs for health service all over the world[2].

Since 2007, Thailand has been changed to an aging society, an increasing trend of elderly population especially with higher number of elderly women[3]. A nation-wide survey [2000-2001] revealed the prevalence of osteoporosis in Thai women aged 40 to 80 years was 13.6% for femoral neck and 19.8% for lumbar spine, respectively. The age-specific prevalence of osteoporosis was more than 50% of Thai postmenopausal women after 70 years of age[4].

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Additionally, the age-adjusted incidence of osteoporotic hip fracture in Thailand was 289 women per 100,000 women[5,6]. This problem is addressed as a current and future significant public health problem and economic burden in Thailand. The goal of osteoporosis management is to prevent osteoporotic fractures. Therefore, early diagnosis is the most important step to prevent the osteoporotic fracture and their consequences.

WHO criteria defined osteoporosis as bone mineral density (BMD) ≤2.5 standard deviation of mean peak bone mass of the young female adult, or T-score ≤ -2.5, measured by dual energy X-ray absorptiometry (DXA) as a gold standard test[7,8]. Although DXA is a gold standard for BMD measurement, it is still imperfect, because of many fractures were reported in individuals who did not meet the bone density criteria for osteoporosis and half of all women with osteoporosis diagnosed by DXA never had fracture[8]. The U.S. Preventive Service Task Force, the National Osteoporosis Foundation and Thai Osteoporosis Practice Guideline recommend that women aged 65 years and older, individuals with history of low traumatic fracture, decrease in height, radiographic osteopenia or vertebral deformity by X-ray, or high risk of osteoporosis by risk assessment tool should be routinely screened for osteoporosis by DXA examination[9,10]. In Thailand, the osteoporotic fracture patients are still under-diagnosed and under-treated for osteoporosis[11] due to limited number of DXA machines, which are available primarily in urban areas due to the cost and logistical difficulties outside the city. Thus, the access to the DXA examination is still the major problem to manage osteoporosis in Thailand.

Quantitative ultrasound (QUS) is one of alternative option of BMD assessment, non-radiation technique, easy, low cost, and portable. It uses low-frequency ultrasound wave and measures into two parameters; the speed of sound (SOS), and the attenuation of ultrasound broad bands (BUA) that can represent both bone density and bone quality such as elasticity and bone micro-architecture[12]. Based on the Thai Young Adult Reference Standard of QUS, we can measure rigidity index (stiffness of bone quantitative ultrasound index: QUI) or stiffness index (SI) and compare this percentage with the standard to create T-score value in the same manner as DXA for diagnose osteoporosis. We found the report of usefulness of QUS (calcaneus) in management of osteoporosis that could predict fracture risk of postmenopausal women and men over the age of 65 years old, similar to what DXA did[13]. The QUS was also correlated well with central BMD measured by DXA at lumbar spine, femoral neck, and total hip[14]. Liu et al [2012] discovered physical loading during QUS measurement improved the diagnosis of osteoporosis[15]. From this point, a lot of benefits can ensue when we employ QUS for the osteoporosis diagnosis, but the problem is no WHO consensus of the optimal cut-point value to diagnose osteoporosis as DXA cut-point of T-score ≤ -2.5 is available. If we could get this cut-point, the QUS can be used as a pre-screening tool to identify individual's high risk of osteoporosis and later refer to perform DXA examination for the definite diagnosis.

The objectives of the present study aimed to determine the optimal cut-point of QUS of the calcaneus for screening osteoporosis in Thai postmenopausal women, and proving the hypothesize that the dynamic stress from standing (loading pressure) would improve the diagnostic characteristic of QUS for osteoporosis, by find out the best position comparing between non-loading and loading position while performing the QUS.

Material and Method

Setting and subjects

The cross-sectional study, enrolled 161 postmenopausal Thai women age 65 years or older who came to BMD evaluation at the Menopause Unit, Department of Obstetrics and Gynecology, Ramathibodi Hospital, Bangkok, Thailand between April 2013 and October 2015. Informed consent was obtained from all subjects.

The exclusion criteria were patients who had histories of the followings, metabolic bone disorder, previous spine, hip, or calcaneus fracture, hip or knee prosthesis, or radiopaque implants, recent administration of radionuclides, abnormal feature of bone at the calcaneus on physical examination, or calcification at calcaneus bone, for example plantar fasciitis and plantar fibroma. In addition, the participants who had ankle sprain and currently took anti-resorptive medication or bone-forming agent other than calcium and vitamin D supplement were also excluded.

Initially the baseline characteristics of patients were collected. Then, QUS of the calcaneus was measured using Achillis Express Ultrasound Device (Lunar, Madison, WI, USA), in the standard sitting or non-weight position for the non-dominant calcaneus and then the QUS was performed on the same side of calcaneus in standing or weight position. The DXA, a

gold standard measurement for BMD at lumbar spine and hip using Hologic QDR-4500 Scanner (Hologic, Waltham, MA, USA) were performed on the same visit of QUS measurement. The osteoporosis was defined if BMD T-score of lumbar spine or femoral neck was ≤ -2.5 SD. The QUS and DXA machines were calibrated before QUS and DXA measurements for preventing of measurement bias. The present study was approved by the Ethical Committee, Ramathibodi Hospital, Mahidol University (ID.03-56-30).

For basic demographics clinical characteristics were used the χ^2 or Fisher's exact test for comparison of categorical variables, while Student's t-test was used for normal distribution data and Mann-Whitney U test was used for non-normal distribution ones. Data were presented as means ± standard deviation (SD), count numbers (n), and percent (%). However, the median (ranges of minimum and maximum value) was shown for non-normal distributed data. The diagnostic performance of each position of QUS of the calcaneus comparing to gold standard DXA of lumbar spine and femoral neck was assessed by the receiver operating characteristic curve (ROC). Differences in area under the curve (AUC) among the positions were calculated using a non-parametric test; and based on the test, an optimal model was selected. All Statistical analysis was performed using STATA Statistical Software Version 14 (College Station, TX, USA).

Table 1. Baseline characteristics of subjects

Baseline characteristics	n (%) (total = 161 cases)
Age (years), median (range)	70 (65, 94)
Years since menopause, median (range)	22 (10, 55)
Height (cm), mean ± SD	152.66±5.95
Weight (kg), mean ± SD	54.92±8.93
Body mass index (kg/m^2), mean ± SD	23.24 (15.89±36.48)
Parity	
Nulliparous	51 (31.68)
Multiparous	110 (68.32)
History of DXA examination	
Yes	94 (58.39)
No	67 (41.61)
History of osteoporotic fracture	
Yes	17 (10.56)
No	144 (89.44)
Family history of osteoporotic fracture	
Yes	18 (11.18)
No	143 (88.82)
Calcium and vitamin D supplement	
Calcium	149 (92.55)
Vitamin D	67 (41.61)

DXA = dual-energy X-ray absorptiometry

Results

One hundred sixty one postmenopausal women participated in the present study. The median (range) age was 70 (65, 94) years old, median (range) time since menopause was 22 (10, 55) years and median (range) of BMI was 23.24 (15.89, 36.48) kg/m^2. The mean ± SD of weight and height were 54.92±8.93 kg and 152.66±5.95 cm, respectively. Sixty-seven women (41.6%) had never received the DXA examination before. Seventeen women (10.5%) had history of osteoporosis fracture at wrist. Most of them (92.55%) were taking daily calcium or calcium plus vitamin D supplement. The baseline characteristics of participants were shown in Table 1. The authors found the prevalence of osteoporosis was 23% at lumbar spine and 30% at femoral neck while the prevalence of osteopenia was 50% at lumbar spine and 56% at neck of femur (Fig. 1, 2).

The diagnostic performance using QUS stiffness index T-score for weight and non-weight position to predict BMD at lumbar spine and femoral neck were shown in Table 2. The maximal area under ROC curve of non-weight QUS of the calcaneus diagnosis of osteoporosis at femoral neck was 0.73, while the weight (standing position) did not improve the diagnostic power.

Table 2. Osteoporosis diagnostic performance of QUS of the calcaneus in non-weight (sitting) and weight (standing) position compare to DXA of the lumbar spine and the neck of femur

QUS methods (compare with DXA)		AUC	Cut-point of QUS T-score	Sensitivity	Specificity	LR+	LR-
Non-weighted QUS	DXA of lumbar spine	0.64	-2.6	77.40	40.50	1.30	0.56
	DXA of neck of femur	0.73	-2.6	81.42	45.83	1.50	0.41
Weighted QUS	DXA of lumbar spine	0.66	-2.4	75.73	46.67	1.42	0.52
	DXA of neck of femur	0.66	-2.4	75.00	42.42	1.30	0.59

QUS = quantitative ultrasound; DXA = dual-energy X-ray absorptiometry; AUC = area under curve; LR+ = positive likelihood ratio; LR- = negative likelihood ratio

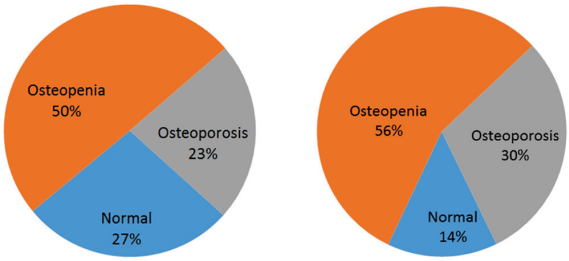

Fig. 1 Categorized of BMD outcome by DXA measurement at lumbar spine (left) and at neck of femur (right), which consists of normal, osteopenia, and osteoporosis.

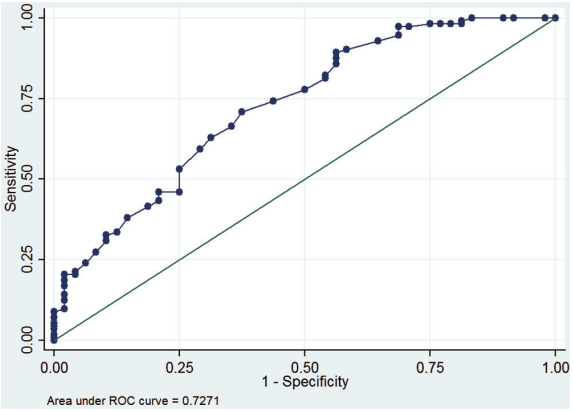

Fig. 2 ROC curve of non-weight QUS of calcaneus for osteoporosis diagnosis at the neck of femur.

From the ROC curve (Fig. 2, Table 3), we determined the optimal cut-point value of QUS of the calcaneus to screen osteoporosis at stiffness index T-score of ≤ -2.6, that represented 81.42% sensitivity and 45.83% specificity. However, this cut-point value was more accurate to predict osteoporosis at femoral neck than at lumbar spine. Finally, we can apply this cut-point for screening due to high sensitivity that enough to recruit population at risk of osteoporosis in order to refer to the definite diagnosis by DXA measurement later.

Discussion

The present study evaluated the diagnostic performance of QUS of the calcaneus comparing to BMD measurement as a gold standard for osteoporosis provided the best AUC at 0.73. The optimal cut-point of stiffness index T-score was at ≤ -2.6 for osteoporosis diagnosis (81.42% sensitivity, and 45.83% specificity). These values were more correlated to osteoporosis at femoral neck than at lumbar spine. Weight (standing

Table 3. Cut-point finding for non-weight QUS of calcaneus for osteoporosis diagnosis at neck of femur

Cut-point of stiffness index T-score	Sensitivity	Specificity	LR+	LR-
≥ -4.7	100.00%	0.00%	1.00	
≥ -4.6	100.00%	2.08%	1.02	0.00
≥ -4.5	100.00%	8.33%	1.09	0.00
≥ -4.3	100.00%	10.42%	1.12	0.00
≥ -4.2	100.00%	16.67%	1.20	0.00
≥ -4.1	99.12%	18.75%	1.22	0.05
≥ -4.0	98.23%	18.75%	1.21	0.09
≥ -3.9	98.23%	20.83%	1.24	0.09
≥ -3.8	98.23%	22.92%	1.27	0.08
≥ -3.6	98.23%	25.00%	1.31	0.07
≥ -3.5	97.35%	29.17%	1.37	0.09
≥ -3.4	97.35%	31.25%	1.42	0.09
≥ -3.3	94.69%	31.25%	1.38	0.17
≥ -3.2	92.92%	35.42%	1.44	0.20
≥ -3.1	90.27%	41.67%	1.55	0.23
≥ -3.0	89.38%	43.75%	1.59	0.24
≥ -2.9	87.61%	43.75%	1.56	0.28
≥ -2.8	85.84%	43.75%	1.53	0.32
≥ -2.7	82.30%	45.83%	1.52	0.39
≥ -2.6	81.42%	45.83%	1.50	0.41*
≥ -2.5	77.88%	50.00%	1.56	0.44
≥ -2.4	74.34%	56.25%	1.70	0.46
≥ -2.3	70.80%	62.50%	1.89	0.47
≥ -2.2	66.37%	64.58%	1.87	0.52
≥ -2.1	62.83%	68.75%	2.01	0.54
≥ -2.0	59.29%	70.83%	2.03	0.57
≥ -1.9	53.10%	75.00%	2.12	0.63
≥ -1.8	46.02%	75.00%	1.84	0.72
≥ -1.7	46.02%	79.17%	2.21	0.68
≥ -1.6	43.36%	79.17%	2.08	0.72
≥ -1.5	41.59%	81.25%	2.22	0.72
≥ -1.4	38.05%	85.42%	2.61	0.73
≥ -1.3	33.63%	87.50%	2.69	0.76
≥ -1.2	32.74%	89.58%	3.14	0.75
≥ -1.1	30.97%	89.58%	2.97	0.77
≥ -1.0	27.43%	91.67%	3.29	0.79
≥ -0.9	23.89%	93.75%	3.82	0.81
≥ -0.8	21.24%	95.83%	5.10	0.82
≥ -0.7	20.35%	95.83%	4.88	0.83
≥ -0.6	20.35%	97.92%	9.77	0.81
≥ -0.5	18.58%	97.92%	8.92	0.83
≥ -0.4	16.81%	97.92%	8.07	0.85
≥ -0.3	14.16%	97.92%	6.80	0.88
≥ -0.2	12.39%	97.92%	5.95	0.89
≥ -0.1	9.73%	97.92%	4.67	0.92
≥0.0	8.85%	100.00%		0.91
≥0.3	7.08%	100.00%		0.93
≥0.4	5.31%	100.00%		0.95
≥0.7	4.42%	100.00%		0.96
≥1.0	3.54%	100.00%		0.96
≥1.1	1.77%	100.00%		0.98
≥2.1	0.88%	100.00%		0.99
>2.1	0.00%	100.00%		1.00

LR+ = positive likelihood ratio; LR- = negative likelihood ratio
* Selected cut-point of stiffness T-score of non-weight QUS of calcaneus ≤ -2.6

position) was not affected to increase the diagnosis performance of QUS of the calcaneus among the menopausal population age older than 65 years. Although the previous study, Liu et al [2012] found that the physical loading while performing QUS of the calcaneus could discriminate between premenopausal women and postmenopausal women more effectively than non-loading[15]. This might be from too small differences among postmenopausal BMD compared to differences between premenopausal BMD and postmenopausal BMD.

In Thailand, the diagnostic performance of QUS of the calcaneus had been investigated by Panichkul et al [2004][16], which included 300 postmenopausal women with mean age of 57.9 years. The study gave the optimal cut-off value for osteoporosis diagnosis of QUS of the calcaneus at the stiffness index 79.5 with 77.6% sensitivity and 59.6% specificity. They used the specificity to rule in and concluded that QUS had low sensitivity and was inappropriate to replace the standard tool, or DXA, for osteoporosis diagnosis. However, there was not mention about the property of screening role of QUS as our study.

Since then, there had been many articles investigated about the diagnostic power of QUS of calcaneus and the osteoporotic fracture[17-19]. The results were promising that QUS of the calcaneus could predict to the end outcome such as hip and vertebral fractures. Recently, meta-analysis of QUS of the calcaneus and the risk fracture assessment on 21 studies found that the relative risk of hip fracture for one standard deviation decrease of stiffness index of QUS of the calcaneus was 2.26 (95% CI 1.71-2.99)[20]. From these reviews, even the QUS of the calcaneus was not in line well with DXA examination, it still correlates to the osteoporotic fractures, especially hip fractures. This supposed to be the ability of QUS to assess both bone density and bone quality while DXA evaluated only bone density.

Comparing with the established screening tools for screening the risk of osteoporosis such as osteoporosis self-assessment tool (OST), the diagnostic performance of QUS of the calcaneus from the present study in high-risk individuals who were indicated for DXA was not inferior to OST. The OST model created from two clinical risk factors of age and body weight. The OST index was calculated as difference of age in years and weight in kilograms multiplied by 0.2. The OST index at -4 and below were defined as high risk of osteoporosis and indicated to further performing the BMD measurement by DXA for osteoporosis diagnosis. From Asian population study, Osteoporosis Self-assessment Tool for Asians (OSTA) revealed the diagnostic performance of OSTA and osteoporosis diagnosis by DXA of OSTA index ≤ -1, differed from other reviews, this cut-point gave the AUC of 0.79, sensitivity of 91% and specificity of 45%[21]. However, the recent systematic review in 2013[22], the OSTA has the diagnostic performance to predict low BMD (BMD T-score ≤ -2 by DXA) of OSTA index ≤ -4 with AUC of 0.65-0.85. That was still controversial about the optimal cut-point of OSTA index for Asians.

We also assessed OSTA index at cut-point ≤ -4, referred by Thai Osteoporosis Practice Guideline, compared to osteoporosis diagnosed by DXA, the diagnosis performance at ROC was equal to 0.77, sensitivity and specificity were 72.58% and 62.16%, respectively, for lumbar spine BMD and ROC was equal to 0.69, sensitivity and specificity were 72.57% and 54.17%, respectively, for neck of femur BMD.

Conclusion

QUS of the calcaneus was acceptable as an alternative tool for screening osteoporosis in postmenopausal woman age ≥65 years. The optimal cut-point of stiffness index T-score at ≤ -2.6 in standard position or non-weight method correlated well with predicting osteoporosis diagnosis by DXA. The results showed higher correlation to the neck of femur than the lumbar spine.

Strength of study

The present study defined the individuals at risk of osteoporosis, firstly by age of 65 years old or more, and then further triaged by BMD measurement of QUS of the calcaneus. Therefore, this is the other strategy and a decision-making tool for identifying the individuals who were reasonably referred for BMD measurement by DXA, suitable for the optimal resource-constrained environments or developing countries.

Furthermore, the present study was the first to clarify the outcome of the loading pressure by standing on QUS examination, but this method was not powerful enough to discriminate the BMD outcome along the postmenopausal population.

Limitation of study

The present study had been designed for evaluating the diagnosis performance of QUS of the calcaneus under the power of 90 percent accuracy to diagnose osteoporosis using DXA as a gold standard.

The main purpose of osteoporosis management is to prevent the osteoporotic fracture, so the final outcome of the study should be the power of QUS to detect individuals with high risk of osteoporosis fracture rather than the osteoporosis diagnosis by DXA. Due to the limitation of the study duration and budgets, we chose the intermediate outcome, or osteoporosis, instead of final outcome, or osteoporotic fracture.

What is already known on this topic?

Currently, the diagnosis of osteoporosis in postmenopausal women has been more interest to bring to the comprehensive treatment and prevention of major risk and their complications. Osteoporotic fractures are one of common problem that occurred in postmenopausal women with osteoporosis that result in disability or death consequences. The enormous cost was expended to treat these complications. Therefore, screening and prevention are the way to care for these patients. The current gold standard in the diagnosis of osteoporosis is still using DXA for measurement of BMD status in postmenopausal, which is more expensive and not sufficient. Furthermore, there is a need for more expertise in the investigation. Additionally, it does not cover the whole country. The concept of bringing QUS in the initial screening begins to gain interest. However, there are not many studies on this. Furthermore, some studies did not find the right value for the screening and diagnosis.

What this study adds?

QUS is one option of BMD assessment. It is non-radiation technique, easy, low cost, and portable. From this research, we compared the diagnostic performance of QUS of the calcaneus and BMD measurement as a gold standard for osteoporosis provided the best AUC at 0.73. The optimal cut-off point of stiffness index T-score was at $\leq$ -2.6 for osteoporosis diagnosis (81.42% sensitivity, and 45.83% specificity). These values were more correlated to osteoporosis at femoral neck than at lumbar spine. Weight (standing position) did not increase the diagnosis performance of QUS of the calcaneus among the menopausal population age older than 65 years.

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การศึกษาหาค่าที่เหมาะสมสำหรับการตรวจวัดความหนาแน่นมวลกระดูกเพื่อคัดกรองผู้ป่วยโรคกระดูกพรุนในสตรีวัยหมดระดูด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้าด้วยวิธีลงน้ำหนักในท่ายืนและไม่ลงน้ำหนักในท่านั่ง

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วัตถุประสงค์: *เพื่อหาค่าที่เหมาะสมของการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัตราซาวด์ที่กระดูกส้นเท้า เพื่อใช้คัดกรองภาวะกระดูกพรุนในสตรีวัยหมดระดู และเปรียบเทียบการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้าระหว่างวิธีวัดในท่านั่ง (ไม่ลงน้ำหนัก) และท่ายืน (ลงน้ำหนัก)*

วัสดุและวิธีการ: *การศึกษาวิจัยแบบตัดขวางในผู้ป่วยสตรีวัยหมดระดูอายุตั้งแต่ 65 ปีขึ้นไป ที่มารับการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่อง dual-energy X-ray absorptiometry (DXA) ที่คลินิกสตรีวัยหมดระดู ภาควิชาสูติศาสตร์-นรีเวชวิทยา คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี ระหว่างเดือนเมษายน พ.ศ. 2557 ถึง ตุลาคม พ.ศ. 2558 โดยมวลเนื้อเยื่อกระดูกถูกวัดและจัดเก็บข้อมูลด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้าในข้างไม่ถนัด ในท่ามาตรฐานท่านั่ง (ไม่ลงน้ำหนัก) และท่ายืน (ลงน้ำหนัก) เพื่อเปรียบเทียบกับค่าที่วัดโดยวิธีวัดความหนาแน่นมวลกระดูกด้วยเครื่อง DXA ของกระดูกหลังส้นหลังส่วนเอวและกระดูกสะโพกโดยตรวจวัดภายในวันเดียวกัน เพื่อนำมาหาวิเคราะห์พื้นที่ใต้กราฟ receiver operating characteristic curve (ROC) ที่สูงที่สุดเพื่อกำหนดจุดตัดที่เหมาะสมสำหรับการวินิจฉัยเพื่อใช้คัดกรองโรคกระดูกพรุน โดยวัด ความไว ความจำเพาะ และค่าบวก-ลบของ likelihood ratio*

ผลการศึกษา: *ผู้ป่วยสตรีวัยหมดระดูจำนวน 161 ราย เข้าร่วมการศึกษา โดยมีค่ากลางอายุ 70 ปี (65-94 ปี) ค่ากลางของระยะเวลาหมดระดู 22 ปี (10-55 ปี) พบว่าร้อยละ 10.5 เคยมีประวัติกระดูกข้อมือหักจากภาวะกระดูกพรุน พบความชุกของภาวะกระดูกพรุนเท่ากับร้อยละ 23 บริเวณกระดูกหลังส่วนเอว และร้อยละ 30 บริเวณคอของกระดูกสะโพกตามลำดับ พื้นที่ใต้กราฟ ROC สำหรับการวินิจฉัยภาวะกระดูกพรุนเท่ากับ 0.73 จากการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้า และพบมีความสัมพันธ์อย่างดีกับการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่อง DXA ของกระดูกสะโพก อย่างไรก็ตามพบว่าการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้าในท่ารับน้ำหนักหรือท่ายืนไม่ช่วยเพิ่มความสามารถในการวินิจฉัยขึ้นมากกว่าเดิม ค่าที่เหมาะสมที่นำมาใช้เป็นจุดตัดสำหรับการคัดกรองภาวะกระดูกพรุน ด้วยวิธีการตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้า โดยใช้ค่า stiffness index ที่ T-Score $\leqslant$ -2.6 ซึ่งมีค่าความไวในการวินิจฉัยเท่ากับร้อยละ 81.4 และค่าความจำเพาะเท่ากับร้อยละ 45.83 ตามลำดับ*

สรุป: *การตรวจวัดความหนาแน่นมวลกระดูกด้วยเครื่องอัลตราซาวด์ที่กระดูกส้นเท้าเพื่อคัดกรองภาวะกระดูกพรุนในสตรีวัยหมดระดูอายุตั้งแต่ 65 ปี สามารถนำมาใช้ได้ดีและมีประสิทธิภาพสำหรับการตรวจคัดกรอง โดยจุดตัดที่เหมาะสมคือ stiffness index T-score $\leqslant$ -2.6*