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Original Research

Association between Serum Creatinine and Osteoporosis in Early Postmenopausal Women: A Cross-Sectional Study

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Abstract

Background: Low bone mineral density (BMD) is the hallmark of osteoporosis, postmenopausal women are more likely to have microarchitectural deterioration and fracture risks. This study aimed to determine the relationship between serum creatinine (sCr) levels and osteoporosis in women who are early postmenopausal. **Methods**: There were 335 early postmenopausal women (age 40–60 years) in Dongguan, China, included in this cross-sectional study. BMD in the lumbar spine, femoral neck, and trochanter was measured using dual-energy X-ray absorptiometry (DXA) and assessed using multivariable-adjusted logistic regression models based on sCr levels obtained during the first DXA examination. **Results**: Without osteoporosis patients had significantly higher sCr levels than osteoporosis patients. Overall, 75 (22.4%) participants (age, 51.3 ± 5.2 years) had osteoporosis. The median sCr level was 55.9 ± 9.6 µmol/L (range, 29.0–94.0 µmol/L). sCr levels increased by 1 µmol/L, while the risk of osteoporosis decreased by 4% (odds ratio [OR], 0.96; 95% confidence interval [95% CI], 0.93–0.99), when menopause duration, menopause rating scale, body mass index, smoking habits, alcohol consumption, activity status, serum uric acid, and serum urea nitrogen were considered. Participants in the highest sCr quantile were at low risk for osteoporosis compared with those in the lowest quantile (OR, 0.46; 95% CI, 0.22–0.94). Based on subgroup and sensitivity analyses, this association remained stable. **Conclusions**: The sCr levels of early postmenopausal women are negatively associated with BMD, independent of age, menopause duration, and serum uric acid levels. As a marker of bone health, sCr may be a valuable indicator of skeletal muscle mass and provide evidence for future osteoporosis markers.

Keywords: osteoporosis; bone mineral density; bone health status; early postmenopausal women; serum creatinine

1. Introduction

Osteoporosis, characterized by low bone mineral density (BMD), microstructural deterioration, and an increased risk of fracture, is particularly prevalent in postmenopausal women [1]. The assessment of osteoporosis' related risk factors can assist clinicians in preventing, diagnosing, and treating it. The loss of muscle mass has been linked to osteoporosis, as reported in epidemiological studies, and reduced skeletal muscle predicts fractures more accurately than BMD and other clinical risk factors [2,3]. Consequently, ongoing studies are investigating how bone health is correlated with several less researched or novel biomarkers, including serum creatinine (sCr) [4]. sCr is one of the main metabolites of skeletal muscle [5]. In addition, since one unit of skeletal muscle contains the same amount of creatinine as one unit of creatine, sCr concentration is directly related to skeletal muscle mass [6]. A steady rate (2% of the total creatine per day) of nonenzymatic conversion has been reported between muscular creatine and sCr, which is excreted by the kidneys into the urine [7]. A person's sCr level is an indicator of the body's renal function and muscle mass [8]. Muscle catabolism generates creatinine, which is dependent on muscle mass [9]. Therefore, systemic muscle mass can be measured using circulating levels of creatinine [10]. Previous studies have found that patients on dialysis and those with end-stage renal disease have higher rates of low BMD and fractures and it is well known that renal function plays a key role in osteoporosis [11–13]. Considering the relationship between bones and muscles based on these findings, the decrease in sCr levels may also be associated with the decrease in BMD in individuals without renal insufficiency. In addition, early postmenopausal women undergo many physical changes due to dramatic hormonal changes in the body. However, a few researches on the association between sCr levels and osteoporosis in early postmenopausal women. For this, the data in a subsample of 335 early postmenopausal women aged 40–60 years for associations with osteoporosis were analyzed.

2. Methods

The current study was conducted at Dongguan Eastern Central Hospital in China in 2020 as a cross-sectional study. All subjects gave their informed consent for inclusion be-

fore they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Dongguan Eastern Central Hospital. Participation in the study was based on the following criteria: natural menopause; age 40–60 years; presence of a uterus; Han nationality; no history of hypertension, diabetes, tumors, or chronic infections related to the heart, brain, lung, kidney, liver, or kidney and liver; not using medication (including steroid therapy, oestrogen therapy, and other treatments); and not using other treatments. Individuals with an estimated glomerular filtration rate (eGFR) $<$60 mL/min/1.73 m^2 (N = 73) were excluded [14]. Participants who met the inclusion criteria attended appointments scheduled at Dongguan Eastern Central Hospital. Fig. 1 illustrates the study flowchart, indicating that 625 selected women who visited the hospital between July 2020 to October 2022 were enrolled in this study. All 625 women underwent testing to determine their red blood cell count, mean platelet volume, sCr level, and serum uric acid level. After the test results were reviewed, 290 additional women were excluded, resulting in a total of 335 participants. After reviewing the study methods and selection process, the Ethics Committee of Dongguan Eastern Central Hospital (approval number: 2020033) approved the study, and forms of informed consent were signed by all participants.

2.1 Outcome Measures

The bone mineral density (BMD) of the lumbar spine was assessed at the Bone Density Testing Laboratory of the Dongguan Eastern Central Hospital using dual-energy X-ray absorption (DXA) (Norland XR-800, Swissray Asia, Taiwan, China). To reduce error probabilities, an experienced operator followed a standardised procedure on the same machine. Before examining each participant, the machine was subjected to a standard quality-control program. After calibration of the software used by the machine, the accuracy of the instrument for measuring BMD was 0.859, and the long-term coefficients of variation were 0.51 at the lumbar spine, femoral neck, and femoral trochanter BMD in the second, third, and fourth lumbar vertebrae; left femoral neck; and left troch were measured. BMD is a measure of weight per square centimetre. The BMD measurements are expressed as grams per square centimetre and divided into the following categories according to the World Health Organization standards [15]: normal (T-score $\geq$–1.0); osteopenia (T-score $<$–1.0 and $>$–2.5); and osteoporosis (T-score $\leq$–2.5). This study defined osteoporosis as two or more T-scores less than –2.5 at the femoral neck, troch, and lumbar spine.

2.2 Clinical Measurements

During the baseline examination, each participant underwent a thorough clinical evaluation and completed a questionnaire. The menopause rating scale (MRS) is a simple and effective tool to evaluate menopausal symptoms, which includes the assessment of 11 common symptoms during menopause, such as hyperhidrosis, palpitations, and insomnia. Baseline measurements were taken without shoes while the participants wore light clothing. A body mass index is calculated by multiplying a person's weight by his or her height. In addition to age and physical exercise, the recorded data included smoking habits (regular/never), alcohol consumption (regular/never), and menopause duration (months). As part of a regular physical activity plan, participants walked for 30 minutes four times a week or performed vigorous physical activity for at least 20 minutes three times a week. A woman was considered postmenopausal if she had amenorrhoea for six consecutive months. There were two groups of participants, osteoporosis-prone and non-osteoporosis-prone.

2.3 Laboratory Measurements

The red blood cell count, mean platelet volume, serum uric acid level, and sCr level (biochemical indicators) were evaluated in the laboratory. During 8:30 AM and 10:00 AM, blood samples were collected from participants that had fasted overnight for at least 8 hours. Testing was performed on all blood samples at Dongguan Eastern Central Hospital's Clinical Laboratory (XT4000i System, Sysmex, Foshan, Guangdong, China; C16000 Integrated System, Architct, Abbott Park, IL, USA). The reference measurement ranges of the red blood cell count and mean platelet volume were 2.3–6.5 $\times$ 10^{12}/L and 6.2–20.3 fL, respectively, and the ranges of the serum uric acid and sCr levels were 121–642 µmol/L and 29–94 µmol/L, respectively. Based on age, sex, race, and sCr, the Modified Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI-ASIA) equations were used to calculate the eGFR because they demonstrated better accuracy, particularly for Asian populations, than the widely used Modification of Diet in Renal Disease technique [16]. The CKD-EPI-ASIA equations were as follows: sCr $\leq$0.7 mg/dL: $eGFR_{CKD\text{-}EPI\text{-}ASIA}$ = 141 $\times$ (sCr/0.7) – 0.329 $\times$ 0.993^{age} $\times$ 1.049 (for females).

2.4 Statistical Analysis

In continuous variables, the mean is expressed as the mean $\pm$ standard deviation. In categorical variables, the number is expressed as the number or proportion. Descriptive analysis was applied to all participants. For categorical variables, chi-squared tests were used and for normal distributions, one-way analysis of variance (ANOVA) was used. Two models were constructed using a logistic regression analysis to investigate the association between sCr and osteoporosis. Using asymptotic and exact methods, we calculated both unadjusted and adjusted estimates. Model 1 was the crude model that was not adjusted for covariates. Among the variables that were adjusted in Model 2 were age, menopause duration, menopause rating scale, body mass index, smoking habits, alcohol consumption,

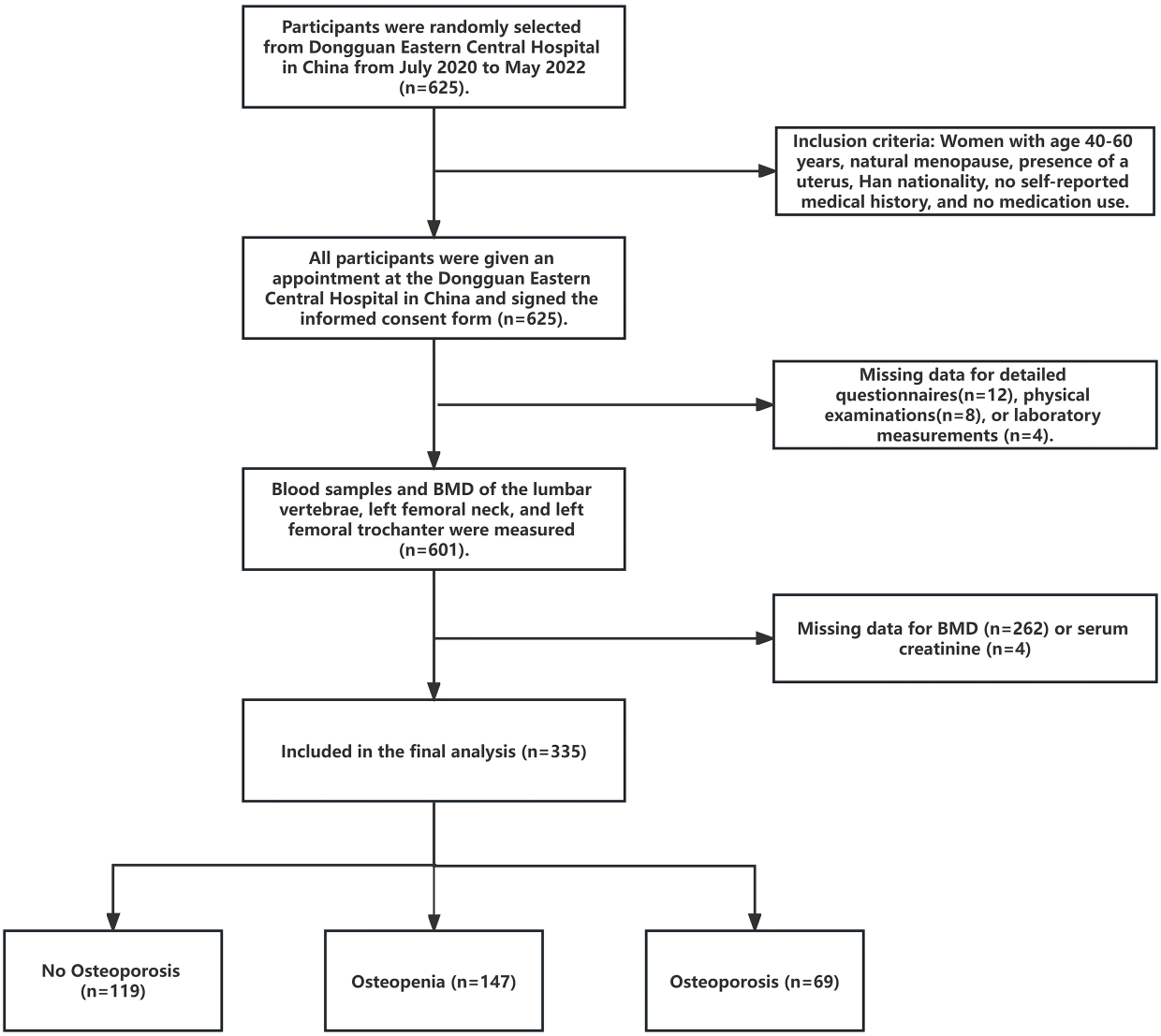

Fig. 1. Participant inclusion flowchart. BMD, bone mineral density.

activity status, serum uric acid, and blood urea nitrogen. To further explore the potential associations, the sCr score was also classified by tripartite (tripartites 1–3) for multivariable logistic regression analyses, and the trend test was also performed. Tripartite 1 showed the lowest sCr levels, and stratified and interaction analyses were performed according to the age group, menopause duration, hyperuricemia, smoking habits, alcohol consumption, and activity status. It was defined as hyperuricemia when the serum uric acid level in women was greater than 420 mol/L. This study was performed using R3.3.2 (http://www.R-project.org; The R Foundation for Statistical Computing, Vienna, Austria) and Free Statistics software version 1.5 (http://www.clinicalscientists.cn/freestatistics/). Two-tailed tests were performed to determine statistical significance.

3. Results

3.1 General Characteristics of the Participants

As shown in Table 1, the baseline characteristics of the 335 early postmenopausal women are summarized. Their mean age was 49.0 $\pm$ 4.9 years, and 75 had osteoporosis. A significant difference was found between participants with osteoporosis and those without osteoporosis in terms of their age and the length of their menopause. A significant reduction in sCr levels was observed in osteoporosis patients. A comparison of the three groups did not reveal significant differences in a number of parameters including MRS, body mass index (BMI), smoking, alcohol consumption, activity, uric acid (UA), and blood urea nitrogen (BUN); however, there were significant differences in red blood cells (RBCs), mean platelet volumes (MPVs), and sCr ($p < 0.05$). In accordance with this, the total BMD mea-

Table 1. Baseline characteristics of the study participants.

	Early postmenopausal women				
	Total (n = 335)	No Osteoporosis (n = 119)	Osteopenia (n = 147)	Osteoporosis (n = 69)	*p*-value
Age (years)	49.0 ± 4.9	46.9 ± 4.1	49.68 ± 4.8	51.2 ± 5.3	<0.001
MT (months)	23.7 ± 23.1	13.52 ± 14.8	25.2 ± 23.516	38.38 ± 25.650	<0.001
MRS	13.4 ± 7.6	13.1 ± 8.2	13.8 ± 7.7	13.0 ± 6.3	0.674
BMI (kg/m^2)	23.9 ± 1.6	23.8 ± 1.7	23.9 ± 1.5	24.0 ± 1.7	0.715
Smoking, n (%)	52 (15.5%)	17 (14.3%)	27 (18.4%)	8 (11.6%)	0.083
Alcohol consumption, n (%)	163 (48.7%)	53 (44.5%)	73 (49.7%)	37 (53.6%)	0.395
Activity, n (%)	122 (36.4%)	49 (41.2%)	53 (36.1%)	20 (29.0%)	0.244
RBC (×10^{12}/L)	4.4 ± 0.5	4.5 ± 0.5	4.5 ± 0.6	4.3 ± 0.6	0.040
MPV (fL)	9.7 ± 1.7	9.9 ± 1.6	9.6 ± 1.5	9.3 ± 2.0	0.046
sCr (μmol/L)	55.9 ± 9.6	56.4 ± 8.9	57.1 ± 9.7	52.2 ± 9.8	0.002
UA (μmol/L)	300.9 ± 81.8	304.9 ± 81.1	305.4 ± 79.8	284.6 ± 86.0	0.176
BUN (mmol/L)	5.0 ± 1.4	4.5 ± 1.1	4.7 ± 1.5	4.5 ± 1.3	0.470
L2–L4 BMD (g/cm^2)	0.9 ± 0.2	1.1 ± 0.1	0.9 ± 0.1	0.7 ± .1	<0.001
L-Total BMD (g/cm^2)	1.0 ± 0.2 (1006.8 ± 176.9)	1166.5 ± 120.0	987.0 ± 96.1	751.6 ± 159.0	<0.001
Fem neck BMD (g/cm^2)	0.8 ± 0.1	0.9 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	<0.001
Troch BMD (g/cm^2)	0.6 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	<0.001
L-hip Total BMD (g/cm^2)	0.8 ± 0.1 (850.7 ± 132.6)	972.1 ± 88.8	815.3 ± 87.2	716.8 ± 98.1	<0.001

The data are expressed as a mean ± standard deviation or as a percentage (%). Students' *t* test or χ^2 test was used to obtain all *p* values. BMD, bone mineral density; MT, menopause time; MRS, menopause rating scale; BMI, body mass index; RBC, red blood cell count; MPV, mean platelet volume; sCr, serum creatinine; UA, serum uric acid; BUN, serum blood urea nitrogen; L2–L4 BMD, total bone mineral density of the second to the fourth lumbar vertebrae; L-Total BMD, total bone mineral density of the lumbar vertebrae; Fem neck BMD, the bone mineral density of the left femoral neck; Troch BMD, the bone mineral density of the left femoral trochanter; L-Thip total BMD, total bone mineral density of the left hip.

surement values for the lumbar spine, femoral neck, and femoral trochanter gradually decreased from groups with no osteoporosis to groups with osteopenia to groups with osteoporosis ($p < 0.05$).

3.2 Correlation between Creatinine and BMD

In Table 2, we performed linear regression analysis and found no linear correlation between creatinine levels and BMD site values ($p > 0.05$).

Table 2. Linear regression analysis with creatinine levels and BMD values.

	β	SE	*p*-value
L2–L4 BMD	6.943	0.118	0.524
L-Total BMD	0.001	0.019	0.913
Fem neck BMD	–5.099	–0.071	0.630
Troch BMD	0.747	0.009	0.952
L-hip Total BMD	0.001	0.021	0.924

L2–L4 BMD, total bone mineral density of the second to the fourth lumbar vertebrae; L-Total BMD, total bone mineral density of the lumbar vertebrae; Fem neck BMD, the bone mineral density of the left femoral neck; Troch BMD, the bone mineral density of the left femoral trochanter; L-hip total BMD, total bone mineral density of the left hip. SE, standard error.

3.3 Association between Creatinine Levels and BMO Status

In Table 3, we summarize the analyses of logistic regression. Both models showed an association between sCr levels and osteoporosis. In the non-adjusted model (Model 1), sCr levels increased by 1 μmol/L, while the risk of osteoporosis decreased by 5% (odds ratio [OR], 0.95; 95% confidence interval [95% CI], 0.92–0.98; $p < 0.05$). In the Model 2, sCr levels increased by 1 μmol/L, and the risk of osteoporosis decreased by 4% (OR, 0.96; 95% CI, 0.93–0.99; $p < 0.05$). Participants in the highest sCr quantile were at a relatively lower risk for osteoporosis than those in the lowest sCr quantile (OR, 0.44; 95% CI, 0.23–0.83; $p < 0.05$) in Model 1, The middle sCr level group had a 58% (OR, 0.42; 95% CI, 0.22–0.78; $p < 0.05$) decrease in osteoporosis risk over the group with the lowest sCr level and that for the highest sCr level group decreased by 56% (OR, 0.44; 95% CI, 0.23–0.83; $p < 0.05$). Furthermore, this relationship remained in the Model 2. Compared with the group with the lowest sCr level, the risk of osteoporosis for the middle sCr level group decreased by 58% (OR, 0.42; 95% CI, 0.21–0.86; $p < 0.05$) and that for the highest sCr level group decreased by 54% (OR, 0.46; 95% CI, 0.22–0.94; $p < 0.05$).

Table 3. Regression analyses using BMD as the dependent variable.

Variable	Model 1	Model 2
	OR (95% CI)	OR (95% CI)
sCr (μmol/L)	0.95 (0.92–0.98)	0.96 (0.93–0.99)
Binary variable		
Quartile 1 (29.00–52.68)	Ref.	Ref.
Quartile 2 (52.90–64.00)	0.42 (0.22–0.78)	0.42 (0.21–0.86)
Quartile 3 (64.22–94.00)	0.44 (0.23–0.83)	0.46 (0.22–0.94)
p-value	0.009	0.027

Model 1: non-adjusted Model. Model 2: adjusted for age, MT, MRS, BMI, smoking habits, alcohol consumption, activity, UA, and BUN. BMD, bone mineral density; BMI, body mass index; BUN, serum blood urea nitrogen; MRS, menopause rating scale; MT, menopause time; OR, odds ratio; 95% CI, 95% confidence interval; sCr, serum creatinine; UA, serum uric acid.

3.4 Differences between Creatinine Categories in Terms of BMD and Other Variables

Based on their urinary creatinine levels, the participants were divided into triplets. During quartile 1 (Q1), 52.90–64.00 μmol/L in Q2, 64.22–94.00 μmol/L in Q3, creatinine in each quartile ranged from 29.00–52.68 μmol/L. No significant trends were observed in Age, MRS, Drinking, Smoking, Activity, menopause time (MT), RBC, and MPV levels as the quantile increased, while there were significant differences in BMI ($p < 0.05$) (Table 4). Osteoporosis at UA and BUN was significantly increased, while decreased at eGFR. Moreover, lumbar spine, femoral neck, and femoral trochanter, L2–L4, L2 osteoporosis was not significantly increased (Fig. 2). There was no significant trend of decreasing BMD with triplets in ascending order in Fig. 2A–C in terms of femoral neck ($p = 0.778$), femoral trochanter ($p = 0.619$), L2–L4 ($p = 0.158$), or L-hip ($p = 0.630$).

4. Discussion

In this study, we determined whether sCr levels are associated with osteoporosis in early postmenopausal women. According to our findings, sCr negatively correlated with osteoporosis risk among early postmenopausal Chinese women aged 40–60. Additionally, this association remained negative in subgroups stratified by age, menopause duration, hyperuricemia, smoking habits, and alcohol consumption.

Under normal renal function conditions, several steps were taken to analyse the relationship between sCr and osteoporosis. First, participants with heart, brain, lung, kidney, rheumatoid, or liver diseases; those with hypertension, diabetes, tumour, or chronic infection; those using hormone replacement therapy; and those with an eGFR <60 mL/min/1.73 m^2 were excluded [14]. Second, in order to clarify the associations between sCr and osteoporosis, the analysis was again adjusted for age, weight, fat mass, among other variables.

In previous studies, abnormal renal function was associated with reduced bone mass [17,18]. sCr is an important measure of kidney function. A high sCr level indicates impaired kidney function. The relationship between high sCr levels and BMD in patients with chronic kidney disease has been reported by several studies [17,19]. A certain amount of creatinine is metabolised by the body when renal function is abnormal. However, renal function impairs sCr excretion, and high sCr levels are not associated with muscle mass [20]. Patients with abnormal renal function also lose bone because of altered calcium and vitamin D metabolism [21,22]. As a result, individuals with renal dysfunction are at risk for osteoporosis when they have high sCr levels. Contrary to previous studies, our study consistently found a positive correlation between sCr and body mass index among patients with normal renal function. This difference is possibly attributable to the difference in renal function affecting sCr. Creatinine is normally metabolised and excreted by individuals with normal renal function. For participants with high sCr responses, muscle mass and physical activity were higher, and sCr was a stable indicator of human muscle metabolism [23]. Consequently, higher sCr levels correspond to greater muscle mass, which protects against osteoporosis in a normal population.

Osteoporosis and sarcopenia are common health problems among postmenopausal women [24]. Reduced muscle mass and sarcopenia are known risk factors for osteoporosis [25]. As muscle mass decreases, falls and fractures are more likely to occur [26]. Increased morbidity and mortality can result from the gradual deterioration of bone and muscle (osteoporosis and sarcopenia) [27]. Sarcopenia is associated with a decrease in BMD and a greater risk of osteoporosis [28–30]. Muscle accounts for 40% of body mass, thereby making it the largest organ of the body [31]. Sarcopenia causes the loss of muscle mass and strength [32]. Several studies have shown that combining sarcopenia and osteoporosis as “movement disorder syndrome” is more inclusive of cases; furthermore, their combination integrates their pathogenesis and unifies them as one therapeutic target [33]. Several strategies can be implemented to improve bone health and reduce fractures. These strategies include early diagnosis and prevention. A protective or risk factor assessment determines whether a particular characteristic or exposure increases the likelihood of developing osteoporosis. A risk assessment may assist in preventing osteoporosis-related fractures by detecting osteoporosis at an early stage [34]. Despite the clarity of the definition of osteoporosis, sarcopenia remains a mystery [35]. The DXA measurement of body composition, including bone density and muscle mass, is currently the gold standard for evaluating body composition [36]; however, because of financial and time constraints, it is not readily accessible by the general population. An increase or decrease in muscle mass may affect the sCr concentration [37]. sCr is a stable marker of skeletal muscle quality, which may be re-

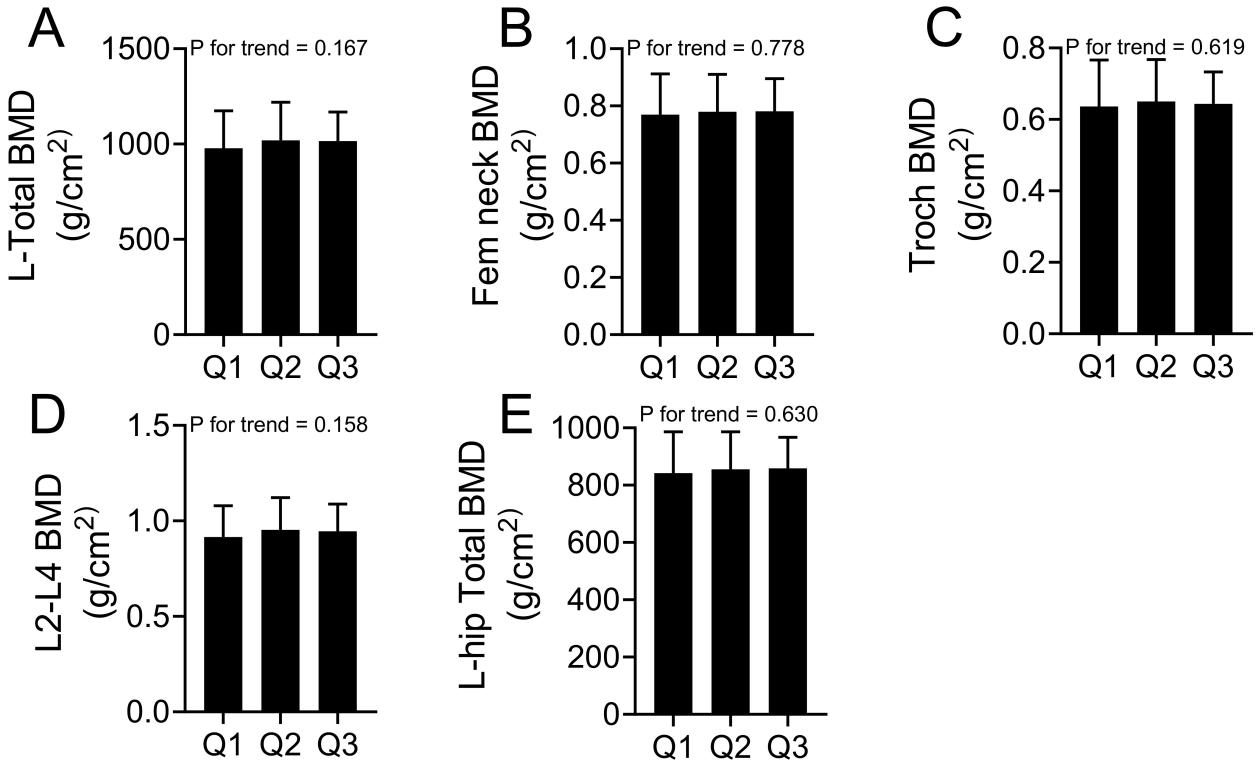

Fig. 2. Graph comparing bone mineral density in the lumbar spine. In the L-Total (A), in the fem neck (B) and in the Troch (C), the L2–L4 (D), and the L-hip Total (E).

Table 4. Baseline characteristics of the tripletes divided according to creatinine.

	Q1 (n = 134)	Q2 (n = 148)	Q3 (n = 53)	*p*-value
Age (years)	49.100 ± 4.836	48.670 ± 5.019	49.700 ± 5.021	0.412
BMI (months)	23.620 ± 1.609	24.100 ± 1.575	23.920 ± 1.588	0.043
MRS (kg/m^2)	12.490 ± 6.673	14.000 ± 8.235	14.060 ± 7.804	0.195
Drinking, n (%)	69.000 (51.500)	63.000 (42.600)	31.000 (58.500)	0.096
Smoking, n (%)	21.000 (15.700)	21 (14.200)	10 (18.900)	0.721
Activity, n (%)	42.000 (31.300)	59.000 (39.900)	21.000 (39.600)	0.289
MT (months)	23.820 ± 21.964	23.260 ± 24.234	24.890 ± 23.329	0.908
RBC (×10^{12}/L)	4.470 ± 0.529	4.430 ± 0.546	4.450 ± 0.589	0.763
MPV (fL)	9.610 ± 1.686	9.740 ± 1.751	9.630 ± 1.351	0.797
eGFR	118.060 ± 15.583	96.360 ± 9.163	78.360 ± 11.005	<0.001*
UA (μmol/L)	281.350 ± 81.144	305.370 ± 76.261	337.960 ± 84.955	<0.001*
BUN	4.730 ± 1.416	4.950 ± 1.294	5.700 ± 1.404	<0.001*
L2–L4 BMD (g/cm^2)	0.920 ± 0.164	0.950 ± 0.169	0.950 ± 0.143	0.158
L-Total BMD (g/cm^2)	977.970 ± 196.212	1019.560 ± 200.023	1015.450 ± 152.745	0.167
Fem neck BMD (g/cm^2)	0.770 ± 0.142	0.780 ± 0.131	0.780 ± 0.114	0.778
Troch BMD (g/cm^2)	0.640 ± 0.130	0.650 ± 0.117	0.640 ± 0.090	0.619
L-hip Total BMD (g/cm^2)	842.280 ± 143.589	855.420 ± 130.686	858.890 ± 107.848	0.630

The data are expressed as a mean ± standard deviation or as a percentage (%). Students' *t* test or χ^2 test was used to obtain all *p* values. BMD, bone mineral density; MT, menopause time; Q, quartile; MRS, menopause rating scale; BMI, body mass index; RBC, red blood cell count; MPV, mean platelet volume; eGFR, estimated glomerular filtration rate; UA, serum uric acid; BUN, serum blood urea nitrogen; L2–L4 BMD, total bone mineral density of the second to the fourth lumbar vertebrae; L-Total BMD, total bone mineral density of the lumbar vertebrae; Fem neck BMD, the bone mineral density of the left femoral neck; Troch BMD, the bone mineral density of the left femoral trochanter; L-hip total BMD, total bone mineral density of the left hip. *$p < 0.05$ (statistical significance).

lated to bone health [38]. Despite this, there is little evidence of a correlation between the sCr level and BMD, especially during early menopause. Based on the Fourth Korea National Health and Nutrition Examination Survey data, Huh *et al*. [39] conducted a cross-sectional study to investigate the relationship between sCr and BMD in older adults with good renal function and provided the first clinical evidence indicating that low sCr is associated with low BMD. These findings provide a basis for further research. In our study, the sCr level was linearly associated with BMD levels of early postmenopausal women, which is consistent with the research results observed during studies performed in South Korea [39]. The sCr level was affected by the eGFR, but we excluded cases of kidney-related diseases from the study population and participants with an eGFR <60 mL/min/1.73 m^2 (N = 73). When participants with normal renal function undergo sCr testing, the body composition analysis can be replaced with an inexpensive and simple method of determining bone health. It is therefore necessary to provide comprehensive health care throughout the menopause period, including a screening of renal function. To some extent, renal function tests may be predictive of BMD.

This study has some limitations. First, because cross-sectional studies only measure once at one point in time and cannot be used to analyze behavior over time or establish long-term trends, the results of this study do not yet establish causal inferences about the association between sCr and osteoporosis in early postmenopausal women. Therefore, a longitudinal study is necessary to clarify the role of creatinine metabolism in bone health. Second, although we considered the effects of medicines and diseases that can affect BMD, unidentified confounders exist. Third, dietary variables including protein, calcium and vitamin D supplements were not measured in this study. Among them, since protein intake can significantly affect sCr levels, we need to reduce the influence of this confounder in further studies.

5. Conclusions

In conclusion, this cross-sectional analysis found an inverse association between sCr levels and BMD among early postmenopausal women. sCr levels can be used to indirectly assess bone and muscle health and to further treat and prevent sarcopenia and low BMD. The relationship between sCr levels and BMD among early postmenopausal women also provide evidence for future markers of osteoporosis.

Availability of Data and Materials

In accordance with the authors' obligations, raw data supporting the article's conclusions will be made available to the public without undue delay.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by YHC and SGZ. The manuscript was written by SHC and RJL. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Dongguan Eastern Central Hospital approved the study (approval number: 2020033).

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Conflict of Interest

The authors declare no conflict of interest.

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