

Case Control Study

Associations between Geriatric Nutrition Risk Index, bone mineral density and body composition in type 2 diabetes patients

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Specialty type: Endocrinology and metabolism**Provenance and peer review:**

Unsolicited article; Externally peer reviewed.

Peer-review model: Single blind**Peer-review report's scientific quality classification**

Grade A (Excellent): 0

Grade B (Very good): 0

Grade C (Good): C, C, C, C, C

Grade D (Fair): 0

Grade E (Poor): 0

P-Reviewer: Chen GX, United States; Di Ciaula A, Italy; Gica N, Romania; Horowitz M, Australia; Yang MW, China**Received:** August 24, 2023**Peer-review started:** August 24, 2023**First decision:** November 21, 2023**Revised:** December 8, 2023**Accepted:** January 24, 2024**Article in press:** January 24, 2024**Published online:** March 15, 2024**Xiao-Xiao Zhu**, Department of Pediatrics, The Second Affiliated Hospital of Nantong University, First People's Hospital of Nantong City, Nantong 226001, Jiangsu Province, China**Kai-Feng Yao, Li-Hua Wang**, Department of Nursing, The Second Affiliated Hospital of Nantong University, First People's Hospital of Nantong City, Nantong 226001, Jiangsu Province, China**Hai-Yan Huang**, Department of Endocrinology, The Second Affiliated Hospital of Nantong University, First People's Hospital of Nantong City, Nantong 226001, Jiangsu Province, China**Corresponding author:** Li-Hua Wang, MNurs, Chief Nurse, Department of Nursing, The Second Affiliated Hospital of Nantong University, First People's Hospital of Nantong City, No. 666 Shengli Road, Nantong 226001, Jiangsu Province, China. wlh512512@163.com

Abstract

BACKGROUND

Type 2 diabetes mellitus (T2DM), a fast-growing issue in public health, is one of the most common chronic metabolic disorders in older individuals. Osteoporosis and sarcopenia are highly prevalent in T2DM patients and may result in fractures and disabilities. In people with T2DM, the association between nutrition, sarcopenia, and osteoporosis has rarely been explored.

AIM

To evaluate the connections among nutrition, bone mineral density (BMD) and body composition in patients with T2DM.

METHODS

We enrolled 689 patients with T2DM for this cross-sectional study. All patients underwent dual energy X-ray absorptiometry (DXA) examination and were categorized according to baseline Geriatric Nutritional Risk Index (GNRI) values calculated from serum albumin levels and body weight. The GNRI was used to evaluate nutritional status, and DXA was used to investigate BMD and body composition. Multivariate forward linear regression analysis was used to identify the factors associated with BMD and skeletal muscle mass index.

RESULTS

Of the total patients, 394 were men and 295 were women. Compared with patients in tertile 1, those in tertile 3 who had a high GNRI tended to be younger and had lower HbA1c, higher BMD at all bone sites, and higher appendicular skeletal

muscle index (ASMI). These important trends persisted even when the patients were divided into younger and older subgroups. The GNRI was positively related to ASMI (men: $r = 0.644$, $P < 0.001$; women: $r = 0.649$, $P < 0.001$), total body fat (men: $r = 0.453$, $P < 0.001$; women: $r = 0.557$, $P < 0.001$), BMD at all bone sites, lumbar spine (L1-L4) BMD (men: $r = 0.110$, $P = 0.029$; women: $r = 0.256$, $P < 0.001$), FN-BMD (men: $r = 0.293$, $P < 0.001$; women: $r = 0.273$, $P < 0.001$), and hip BMD (men: $r = 0.358$, $P < 0.001$; women: $r = 0.377$, $P < 0.001$). After adjustment for other clinical parameters, the GNRI was still significantly associated with BMD at the lumbar spine and femoral neck. Additionally, a low lean mass index and higher β -collagen special sequence were associated with low BMD at all bone sites. Age was negatively correlated with ASMI, whereas weight was positively correlated with ASMI.

CONCLUSION

Poor nutrition, as indicated by a low GNRI, was associated with low levels of ASMI and BMD at all bone sites in T2DM patients. Using the GNRI to evaluate nutritional status and using DXA to investigate body composition in patients with T2DM is of value in assessing bone health and physical performance.

Key Words: Geriatric Nutrition Risk Index; Bone mineral density; Skeletal muscle mass; Type 2 diabetes

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Core Tip: Osteoporosis and sarcopenia are highly prevalent in type 2 diabetes mellitus (T2DM) patients. In people with T2DM, the association between nutrition, sarcopenia, and osteoporosis has rarely been explored. We observed that poor nutrition, as indicated by a low Geriatric Nutritional Risk Index (GNRI), was associated with low levels of ASMI and bone mineral density at all bone sites in T2DM patients. Using the GNRI to evaluate nutritional status and using dual energy X-ray absorptiometry to investigate body composition in patients with T2DM is of value in assessing bone health and physical performance.

Citation: Zhu XX, Yao KF, Huang HY, Wang LH. Associations between Geriatric Nutrition Risk Index, bone mineral density and body composition in type 2 diabetes patients. *World J Diabetes* 2024; 15(3): 403-417

URL: <https://www.wjgnet.com/1948-9358/full/v15/i3/403.htm>

DOI: <https://dx.doi.org/10.4239/wjd.v15.i3.403>

INTRODUCTION

Over the past few years, there has been a rise in the prevalence of osteoporosis and sarcopenia among the elderly population, leading to physical impairment, diminished quality of life and even death of patients[1,2]. Type 2 diabetes mellitus (T2DM), a rapidly growing public health problem, is one of the most common chronic metabolic disorders in older individuals[3]. For patients with T2DM, osteoporosis is one of the possible long-term complications[4]. Sarcopenia, or loss of muscle mass and function, is a major cause of disability in diabetes[5]. Therefore, it is imperative to identify early sarcopenia, osteoporosis and their risk factors in older individuals with T2DM. Subsequently, suitable measures should be taken to avert and manage this ailment.

As a multifactorial systemic disease, many factors contribute to sarcopenia, such as age, sex, body mass index (BMI), duration of diabetes, glycemic control, nutritional status, and lifestyle[6-8]. Sarcopenia is commonly believed to be a decline in skeletal muscle mass and reduced muscle function that occurs with age. In sarcopenia research, the Asia Working Group for Sarcopenia suggests the utilization of the skeletal muscle index (SMI). This index is calculated by dividing the appendicular skeletal muscle mass (ASMM) by the square of height, providing an adjusted measurement of muscle mass[9]. The factors associated with osteoporosis in T2DM include age, sex, BMI, serum vitamin D concentrations, lifestyle factors, duration of diabetes[10], and nutritional risk[11]. Since there are several common factors in osteoporosis and sarcopenia, many studies of the association between osteoporosis and skeletal muscle mass have been reported. The connection between low muscle mass and osteoporosis in patients with T2DM remains uncertain.

Malnutrition is frequently found in elderly individuals. Older adults with T2DM may face an increased risk of undernutrition due to excessively strict dietary habits aimed at managing blood sugar levels[12]. Various tools have been developed to assess malnutrition status, including the Malnutrition Screening Tool[13], Malnutrition Universal Screening Tool[14], Mini Nutritional Assessment Short Form[15], Nutrition Risk Score 2002[16], and Geriatric Nutritional Risk Index (GNRI)[17]. The GNRI has been utilized as a convenient and accessible method among these instruments for assessing outcomes, relying on serum albumin levels and the ratio of real body weight to ideal body weight.

The relationship between nutritional status and bone mass has been observed in different populations, such as individuals with chronic obstructive pulmonary disease[18], rheumatoid arthritis[19,20], and end-stage renal disease[21]. In people with T2DM, nutrition, sarcopenia, and osteoporosis are rarely explored. Therefore, in this study, we investigated associations between bone mineral density (BMD), the GNRI and body composition in patients with T2DM.

MATERIALS AND METHODS

Study design and participants

We conducted a retrospective cross-sectional study among T2DM patients admitted to the Department of Endocrinology, The Second Affiliated Hospital of Nantong University, between January 1, 2020, and March 1, 2022.

Patients

The main inclusion criterion in this study was T2DM. T2DM was defined as a fasting blood glucose level of > 7.0 mmol/L and/or a 2-h postprandial blood glucose level > 11.1 mmol/L in an oral glucose tolerance test, in accordance with the 1999 World Health Organization T2DM diagnosis and classification criteria. The patients were excluded based on the following criteria: (1) Malignant tumor and severe heart, cerebral, liver or kidney diseases; (2) pituitary, thyroid, parathyroid and adrenal diseases; (3) treatment with glucocorticoids or sex hormones in the past 6 mo; (4) concomitantly taking drugs affecting bone metabolism, such as calcium, vitamin D and bisphosphonates; and (5) unavailability of complete data on relevant variables and assessments. This study was approved by the ethics committee of The Second Affiliated Hospital of Nantong University and was in line with the Helsinki Declaration. The number for ethics approval was 2021KT063.

Data collection

Collection of demographic, medical, and laboratory data: All demographic information and relevant medical histories of the participants were recorded from their medical records. Demographic data included age, sex, height, weight and BMI. Body weight and height were measured with the patient lightly clothed and without shoes. BMI (kg/m^2) was calculated as body weight in kilograms divided by height in meters squared. Medical history included diabetes duration and history of hypertension. The duration of diabetes was calculated by months from the time that the patient was diagnosed with T2DM in their medical records to the date we took blood tests. We also collected the glucose-lowering therapy status among participants. Glucose-lowering therapies were categorized as lifestyle alone and drug therapy. Hypoglycemic agents included insulin, insulin secretagogues, insulin sensitizers, metformin, AGIs (α -glucosidase inhibitors), DPP-4Is (dipeptidyl peptidase-4 inhibitors), SGLT-2Is (sodium-glucose cotransporter-2 inhibitors) and GLP-1RAs (glucagon-like peptide-1 receptor agonists).

For laboratory data collection, the nurses in the ward took blood samples from the antecubital vein in the early morning hours after overnight fasting (at least 8 h). Triglycerides (TGs; colorimetric method), total cholesterol (TC; cholesterol oxidase method), low-density lipoprotein cholesterol (LDL-C; selective melting method) and high-density lipoprotein cholesterol (HDL-C; enzyme modification method) were measured by an automatic biochemical instrument (Model 7600, Hitachi). The level of HbA1c was assessed by ion exchange high-performance liquid chromatography. The levels of bone metabolism markers, including osteocalcin (OS), β -collagen special sequence (β -CTX) and total type I procollagen N-terminal extension peptide (TP1NP). Additionally, other biochemical markers, such as serum creatinine (Cr), uric acid (UA), albumin and total bilirubin (TBil), were measured according to standard methodology.

BMD and body composition measurements: BMD and body composition were measured using dual energy X-ray absorptiometry (DXA; Hologic-Discovery Wi, S/N86856). All of the patients were scanned, and calculations were performed by professionals in the corresponding medical and technical departments. According to the instrument manual, all operations were carried out in the standard mode: The patient lay flat and was scanned from head to feet. The measured indices included lumbar spine (L1-L4) BMD (LS-BMD), femoral neck BMD (FN-BMD), hip BMD, total (whole-body) BMD, total body fat, the android/gynoid ratio, fat mass index, lean mass index and appendicular SMI (ASMI). BMD (g/cm^2) was calculated using the following formula: Bone mineral content (g)/area (cm^2); ASMI was calculated by limb skeletal muscle mass: ASMM (kg)/height² (m^2); lean mass index was calculated using the following formula: Lean mass (kg)/height² (m^2); and fat mass index was calculated using the following formula: Fat mass (kg)/height² (m^2).

Calculation of the GNRI

Based on the serum albumin level and baseline body weight, the GNRI is calculated as follows: $\text{GNRI} = [1.489 \text{ albumin (g/L)} + (\text{weight/ideal weight})]$. Ideal weight can be further calculated by the following equations: Men: Ideal weight = height (cm) - 100 - [(height - 150)/4]; Women: Ideal weight = height (cm) - 100 - [(height - 150)/2.5].

Statistical analysis

The patients were classified by GNRI tertiles with cutoff values of < 101.85 , 101.85 to 109.52, and > 109.52 . A descriptive analysis of the data was performed based on the type of data, including the mean and standard deviation, and frequency and percentage. The trends of continuous data and categorical data were detected using one-way ANOVA with linear polynomial contrasts, Kruskal-Wallis tests, and Chi-squared tests with linear-by-linear associations. Furthermore, we generated scatter plots using GraphPad Prism to show the correlation between the GNRI and BMD, ASMI, and total body fat (T-FAT). The factors associated with BMD and ASMI were identified using multiple stepwise linear regression analyses.

For the statistical analysis, we employed IBM SPSS Statistics (25.0) and GraphPad Prism (9.0). Statistical significance was determined using a *P* value less than 0.05. Normally distributed values are given as the mean $\pm$ SD, skewed distributed values are given as the median (25% and 75% interquartiles), and categorical variables are given as frequency (percentage).

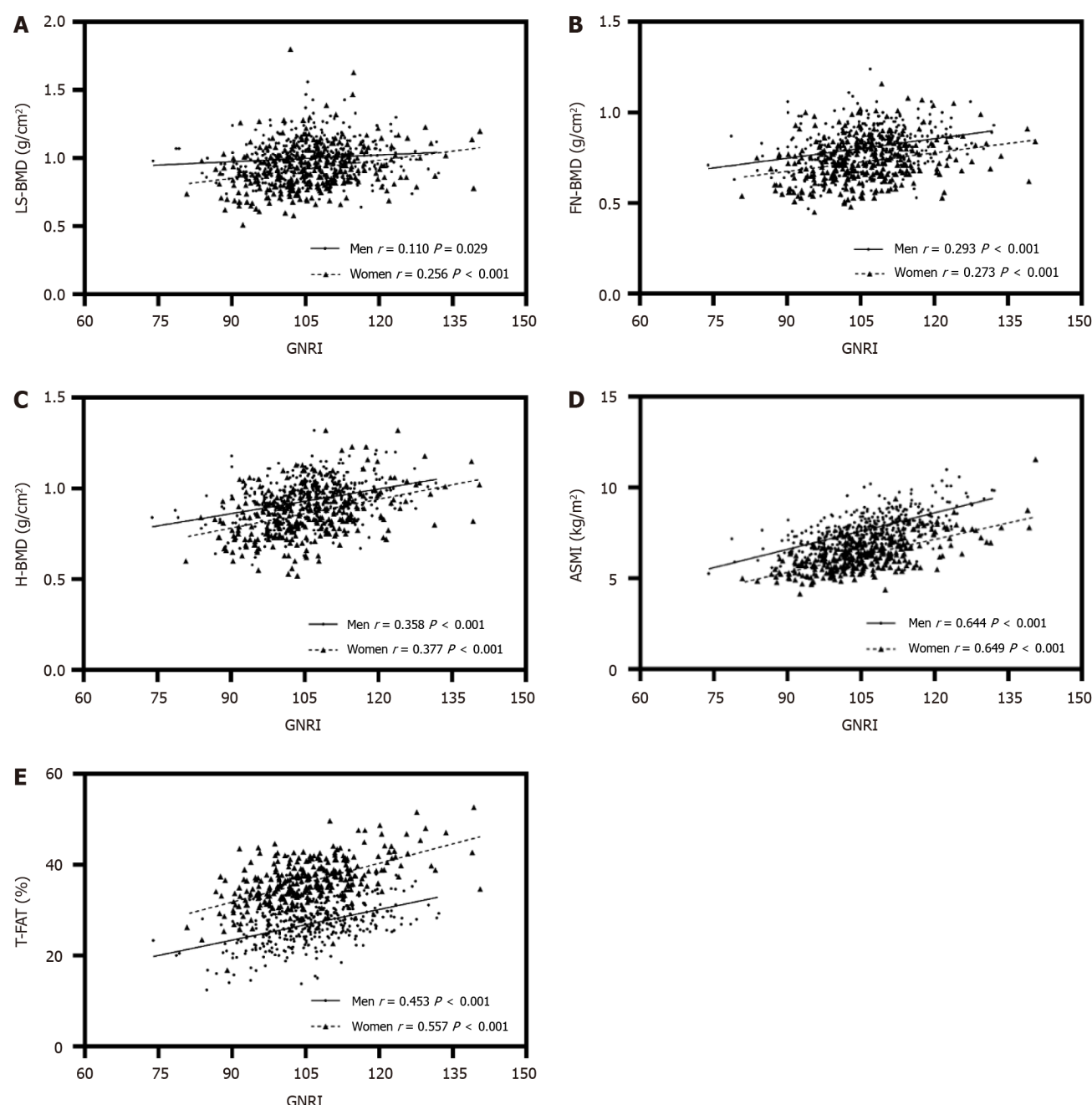


Figure 1 Scatter diagrams showing the correlation between Geriatric Nutritional Risk Index, bone mineral density, total body fat and appendicular skeletal muscle index. A: Lumbar spine (L1-L4) bone mineral density (BMD); B: Femoral neck BMD; C: Hip BMD; D: Appendicular skeletal muscle index; E: Total (whole-body) BMD. BMD: Bone mineral density; GNRI: Geriatric Nutritional Risk Index; LS-BMD: Lumbar spine (L1-L4) bone mineral density; FN-BMD: Femoral neck bone mineral density; H-BMD: Hip bone mineral density; T-FAT: Total body fat.

RESULTS

In this study, we enrolled 689 patients (57.2% men and 42.8% women), with a mean age of 55.59 ± 10.88 years.

Patient characteristics

Table 1 shows comparisons of the characteristics of the patients classified by GNRI tertiles. Compared with patients in tertile 1, those in tertile 3 tended to be younger, had lower HbA1c and β -CTX, and had higher BMI, BMD, total body fat, android/gynoid ratio, fat mass index, lean mass index, ASMI, albumin, UA, TG, TC and TBil. These important trends persisted even when the patients were divided into younger and older subgroups (Tables 2-4).

Associations between GNRI, BMD, T-FAT and ASMI

Figure 1 shows the correlation between GNRI, BMD, T-FAT and ASMI in T2DM patients; the average BMD at the lumbar spine, femur neck and total hip in men was higher than that in women (1.00 vs 0.92, 0.81 vs 0.73, 0.94 vs 0.86, respectively, and all $P < 0.001$); the GNRI was found to be positively and significantly associated with ASMI, T-FAT and BMD at all

Table 1 Comparison of baseline characteristics among type 2 diabetes mellitus patients stratified by tertiles of the Geriatric Nutritional Risk Index

Characteristics	Total (n = 689)	GNRI tertile 1 (n = 230)	GNRI tertile 2 (n = 230)	GNRI tertile 3 (n = 229)	F/H/ χ^2	P value
Women [n (%)]	295 (42.8)	109 (47.4)	96 (41.7)	90 (39.3)	3.065	0.080
Age (yr)	55.59 ± 10.88	58.02 ± 10.49	56.00 ± 10.84	52.74 ± 10.69	28.071	< 0.001
Height (cm)	166.89 ± 8.24	165.25 ± 7.88	167.10 ± 8.52	168.33 ± 8.06	16.410	< 0.001
Weight (kg)	70.00 (62.00-80.00)	62.00 (56.00-69.00)	71.00 (64.75-78.85)	80.00 (72.75-90.00)	16.636	< 0.001
Diabetes duration (yr)	7.33 ± 6.20	8.96 ± 6.42	7.58 ± 6.44	5.45 ± 5.15	38.741	< 0.001
BMI (kg/m ²)	25.39 (23.23-27.78)	22.92 (21.31-24.49)	25.53 (24.20-26.93)	28.28 (26.62-30.47)	19.284	< 0.001
SBP (mmHg)	133.84 ± 15.34	132.96 ± 16.80	133.89 ± 15.98	134.67 ± 12.98	1.420	0.234
DBP (mmHg)	81.00 ± 9.88	79.44 ± 10.19	80.76 ± 9.50	82.79 ± 9.70	13.343	< 0.001
Hypertension [n (%)]	333 (48.3)	112 (48.7)	117 (50.9)	104 (45.4)	0.492	0.483
GNRI (score)	105.61 (99.64-112.01)	97.09 (93.02-99.66)	105.62 (103.73-107.68)	114.25 (112.01-119.37)	27.818	< 0.001
Glucose-lowering therapies [n (%)]						
Lifestyle alone	121 (17.6)	31 (13.5)	36 (15.7)	54 (23.6)	8.071	0.004
Insulin treatments	248 (36.0)	102 (44.3)	89 (38.7)	57 (24.9)	18.817	< 0.001
Insulin secretagogues	222 (32.2)	83 (36.1)	78 (33.9)	61 (26.6)	4.681	0.030
Insulin sensitizers	79 (11.5)	25 (10.9)	28 (12.2)	26 (11.4)	0.027	0.870
Metformin	322 (46.7)	88 (38.3)	110 (47.8)	124 (54.1)	11.622	< 0.001
AGIs	105 (15.2)	23 (10.0)	33 (14.3)	49 (21.4)	11.519	< 0.001
DPP-4Is	57 (8.3)	18 (7.8)	23 (10.0)	16 (7.0)	0.105	0.745
SGLT-2Is	93 (13.5)	28 (12.2)	35 (15.2)	30 (13.1)	0.085	0.771
GLP-1RAs	41 (6.0)	3 (1.3)	14 (6.1)	24 (10.5)	17.240	< 0.001
Statins	122 (17.7)	37 (16.1)	45 (19.6)	40 (17.5)	0.151	0.698
Laboratory findings						
HbA1c (%)	8.99 ± 1.85	9.50 ± 2.02	8.92 ± 1.63	8.53 ± 1.75	33.073	< 0.001
Albumin (g/L)	38.50 (36.20-41.30)	35.90 (33.88-37.63)	38.60 (37.00-40.60)	41.70 (39.45-44.00)	17.954	< 0.001
Cr (μmol/L)	58.51 ± 21.32	58.22 ± 25.22	57.85 ± 21.58	59.46 ± 16.26	0.386	0.535
UA (μmol/L)	312.68 ± 99.25	279.47 ± 103.09	314.02 ± 89.46	344.68 ± 94.19	53.222	< 0.001
TG (mmol/L)	1.89 (1.18-3.11)	1.46 (0.98-2.33)	1.81 (1.15-2.83)	2.38 (1.58-3.98)	7.626	< 0.001
TC (mmol/L)	4.41 ± 1.06	4.29 ± 1.01	4.33 ± 0.98	4.62 ± 1.15	10.890	0.001
HDL-C (mmol/L)	1.14 ± 0.27	1.15 ± 0.28	1.15 ± 0.25	1.10 ± 0.27	3.679	0.056
LDL-C (mmol/L)	2.81 ± 0.87	2.80 ± 0.88	2.80 ± 0.82	2.84 ± 0.91	0.309	0.578
TBil (μmol/L)	11.21 ± 4.71	10.25 ± 4.60	11.43 ± 4.68	11.95 ± 4.70	15.213	< 0.001
OS (ng/mL)	11.85 ± 3.99	12.06 ± 4.26	11.88 ± 3.89	11.60 ± 3.82	1.508	0.220
β-CITX (ng/mL)	0.45 ± 0.22	0.51 ± 0.25	0.44 ± 0.21	0.41 ± 0.19	25.645	< 0.001
TP1NP (ng/mL)	40.73 ± 14.53	41.00 ± 14.00	40.74 ± 14.66	40.45 ± 14.98	0.165	0.685
DXA parameters (g/cm²)						
LS-BMD	0.97 ± 0.16	0.92 ± 0.14	0.99 ± 0.17	0.99 ± 0.15	22.118	< 0.001
FN-BMD	0.77 ± 0.12	0.73 ± 0.12	0.79 ± 0.13	0.81 ± 0.11	53.333	< 0.001
H-BMD	0.91 ± 0.13	0.85 ± 0.12	0.91 ± 0.13	0.95 ± 0.12	83.980	< 0.001

T-BMD	1.10 ± 0.12	1.07 ± 0.12	1.10 ± 0.12	1.12 ± 0.11	21.875	< 0.001
Body composition						
Total body fat (%)	31.03 ± 6.56	29.03 ± 6.55	30.80 ± 5.83	33.26 ± 6.62	51.017	< 0.001
Android/gynoid ratio	1.31 ± 0.22	1.23 ± 0.22	1.33 ± 0.21	1.36 ± 0.20	49.682	< 0.001
Fat mass index (kg/m ²)	7.53 (6.20-9.09)	6.33 (5.08-7.53)	7.54 (6.44-8.74)	8.91 (7.51-10.75)	13.010	< 0.001
Lean mass index (kg/m ²)	16.95 (15.53-18.54)	15.66 (14.44-16.83)	17.11 (15.92-18.39)	18.60 (16.99-19.90)	14.055	< 0.001
ASMI (kg/m ²)	7.09 ± 1.17	6.38 ± 0.91	7.09 ± 0.97	7.79 ± 1.1	218.066	< 0.001

BMI: Body mass index; SBP: Systolic/diastolic blood pressure; DBP: Diastolic blood pressure; GNRI: Geriatric nutritional risk index; AGIs: α -glucosidase inhibitors; DPP-4Is: Dipeptidyl peptidase-4 inhibitors; SGLT-2Is: Sodium-glucose cotransporter-2 inhibitors; GLP-1RAs: Glucagon-like peptide-1 receptor agonists; Cr: Creatinine; UA: Uric acid; TG: Triglyceride; TC: Total cholesterol; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; TBil: Total bilirubin; OS: Osteocalcin; β -CTX: β -collagen special sequence; TP1NP: Total type I procollagen N-terminal extension peptide; DXA: Dual energy X-ray absorptiometry; LS-BMD: Lumbar spine (L1-L4) bone mineral density; FN-BMD: Femoral neck bone mineral density; H-BMD: Hip bone mineral density; T-BMD: Total (whole-body) bone mineral density; ASMI: Appendicular skeletal muscle index.

bone sites in men and women; Table 5 shows multiple linear regression models displaying associations of the GNRI with BMD; the fully adjusted Model 3 further adjusted for HbA1c, OS, β -CTX, TP1NP, albumin, Cr, UA, TG, TC, HDL-C, LDL-C, TBil, and the GNRI was significantly and positively associated with LS-BMD ($b = 0.040$, $t = 2.492$, $P = 0.013$, $R^2 = 0.197$) and FN-BMD ($b = 0.027$, $t = 2.345$, $P = 0.019$, $R^2 = 0.341$).

Multivariate forward linear regression analysis of the determinants of BMD and ASMI

Table 6 shows the determinants of BMD using multivariate stepwise linear regression analysis after adjusting for age, sex, height, weight, diabetes duration, hypertension, systolic/diastolic blood pressure (SBP), diastolic blood pressure (DBP), GNRI, BMI, HbA1c, OS, β -CTX, TP1NP, albumin, Cr, UA, TG, TC, HDL-C, LDL-C, TBil, ASMI, total body fat, android/gynoid ratio, fat mass index and lean mass index; the lean mass index was positively correlated with BMD at all bone sites; age, diabetes duration and β -CTX were negatively correlated with BMD at all bone sites; height and Cr were positively correlated with lumbar spine BMD, whereas albumin and ASMI were negatively correlated with lumbar spine BMD; albumin and the android/gynoid ratio were negatively correlated with femoral neck BMD, whereas height was positively correlated with femoral neck BMD; weight was positively correlated with total hip BMD, whereas the android/gynoid ratio was negatively correlated with total hip BMD.

Table 7 shows the determinants of ASMI using multivariate forward linear regression analysis after adjusting for age, sex, height, weight, diabetes duration, hypertension, SBP, DBP, GNRI, BMI, HbA1c, OS, β -CTX, TP1NP, albumin, Cr, UA, TG, TC, HDL-C, LDL-C and TBil; in men, age, diabetes duration and HbA1c were negatively correlated with ASMI, whereas weight and BMI were positively correlated with ASMI; in women, weight and OS were positively correlated with ASMI, whereas age, height, TBil and β -CTX were negatively correlated with ASMI.

DISCUSSION

This study investigated associations among GNRI, BMD, and ASMI in T2DM patients. In this research, we discovered that proper nutrition, as denoted by a high GNRI, was linked to a lower HbA1c, higher BMD at all bone sites, higher lean mass index and higher ASMI. Based on prior research, this study utilized the GNRI and found that the GNRI was positively related to ASMI and BMD at all bone sites in T2DM patients. Additionally, a low lean mass index and higher β -CTX were associated with low BMD at all bone sites. Age was negatively correlated with ASMI, whereas weight was positively correlated with ASMI.

Despite the appropriate consumption, the nutrition of patients with T2DM was significantly impacted[22]. Diabetes speeds up the decline of muscle power, quality and serum albumin, highlighting the importance of maintaining a proper balance of protein and energy in one's diet. The current investigation demonstrated that a decreased GNRI posed a notable hazard for diminished BMD and ASMI among individuals with T2DM. This finding is consistent with previous studies[23]. Studies have demonstrated that the GNRI can be applied as a convenient and reliable indicator of the BMD and ASMI conditions of patients with chronic hepatitis C[24], postmenopausal women who have undergone total thyroidectomy[25] and patients receiving hemodialysis[26]. Therefore, the GNRI might be a convenient and reliable indicator of BMD and ASMI status in patients with T2DM. As albumin level reflects protein status and is a major component of the GNRI, the effect of protein on bone and muscle may help to explain the associations between GNRI, BMD and ASMI.

The second important finding of this study is that a low GNRI was associated with a higher HbA1c. This indicates that the presence of malnutrition is not conducive to blood sugar control. In addition to drug therapy, the basic treatment regimen for type 2 diabetes patients is diet restriction and exercise to achieve the goal of controlling blood sugar. Malnutrition can result if there is no strict and regular diet strategy. A previous study has proven that hyperglycemia contributes to the accelerated decline in muscle mass among patients with T2DM[27]. Higher HbA1c levels may lead to

Table 2 Comparison of baseline characteristics among type 2 diabetes mellitus patients stratified by the tertiles of age

Characteristics	Total (n = 689)	Younger ¹ (n = 219)	Older ² (n = 470)	$\chi^2/t/z$	P value
Women [n (%)]	295 (42.8)	111 (50.7)	184 (39.1)	8.120	0.004
Age (yr)	55.59 ± 10.88	43.71 ± 7.23	61.12 ± 7.25	-29.374	< 0.001
Height (cm)	166.89 ± 8.24	167.33 ± 8.55	166.69 ± 8.1	0.951	0.342
Weight (kg)	70.00 (62.00-80.00)	71.00 (62.00-82.00)	70.00 (62.00-80.00)	-1.178	0.239
Diabetes duration (yr)	7.33 ± 6.20	4.44 ± 3.82	8.68 ± 6.62	-10.603	< 0.001
BMI (kg/m ²)	25.39 (23.23-27.78)	25.42 (23.11-28.34)	25.39 (23.32-27.55)	-1.001	0.317
SBP (mmHg)	133.84 ± 15.34	128.84 ± 13.78	136.16 ± 15.49	-5.977	< 0.001
DBP (mmHg)	81.00 ± 9.88	81.74 ± 10.15	80.65 ± 9.75	1.342	0.180
Hypertension [n (%)]	333 (48.3)	66 (30.1)	267 (56.8)	42.556	< 0.001
GNRI (score)	105.61 (99.64-112.01)	107.2 (101.18-113.56)	105.09 (98.93-110.98)	-2.880	0.004
Glucose-lowering therapies					
Lifestyle alone [n (%)]	121 (17.6)	58 (26.5)	63 (13.4)	17.653	< 0.001
Insulin treatments [n (%)]	248 (36.0)	73 (33.3)	175 (37.2)	0.987	0.321
Insulin secretagogues [n (%)]	222 (32.2)	44 (20.1)	178 (37.9)	21.627	< 0.001
Insulin sensitizers [n (%)]	79 (11.5)	20 (9.1)	59 (12.6)	1.722	1.189
Metformin [n (%)]	322 (46.7)	92 (42.0)	230 (48.9)	2.880	0.090
AGIs [n (%)]	105 (15.2)	29 (13.2)	76 (16.2)	0.992	0.319
DPP-4Is [n (%)]	57 (8.3)	19 (8.7)	38 (8.1)	0.069	0.793
SGLT-2Is [n (%)]	93 (13.5)	26 (11.9)	67 (14.3)	0.727	0.394
GLP-1RAs [n (%)]	41 (6.0)	15 (6.8)	26 (5.5)	0.463	0.496
Statins [n (%)]	122 (17.7)	38 (17.4)	84 (17.9)	0.028	0.868
Laboratory findings					
HbA1c (%)	8.99 ± 1.85	8.99 ± 1.9	8.98 ± 1.82	0.075	0.941
Albumin (g/L)	38.50 (36.20-41.30)	39.00 (36.8-41.6)	38.25 (35.8-41)	-2.470	0.014
Cr (μmol/L)	58.51 ± 21.32	52.09 ± 12.75	61.5 ± 23.74	-6.750	< 0.001
UA (μmol/L)	312.68 ± 99.25	317.68 ± 112.65	310.35 ± 92.39	0.903	0.367
TG (mmol/L)	1.89 (1.18-3.11)	1.99 (1.28-3.41)	1.78 (1.15-2.87)	-1.940	0.052
TC (mmol/L)	4.41 ± 1.06	4.5 ± 1.09	4.37 ± 1.04	1.475	0.141
HDL-C (mmol/L)	1.14 ± 0.27	1.09 ± 0.25	1.16 ± 0.27	-3.049	0.002
LDL-C (mmol/L)	2.81 ± 0.87	2.85 ± 0.87	2.79 ± 0.87	0.803	0.422
TBil (μmol/L)	11.21 ± 4.71	10.99 ± 4.28	11.31 ± 4.89	-0.836	0.404
OS (ng/mL)	11.85 ± 3.99	11.93 ± 3.43	11.81 ± 4.23	0.409	0.683
β-CITX (ng/mL)	0.45 ± 0.22	0.47 ± 0.21	0.45 ± 0.23	1.137	0.256
TPINP (ng/mL)	40.73 ± 14.53	41.58 ± 13.84	40.34 ± 14.84	1.044	0.297
DXA parameters (g/cm²)					
LS-BMD	0.97 ± 0.16	1.00 ± 0.14	0.95 ± 0.16	4.126	< 0.001
FN-BMD	0.77 ± 0.12	0.82 ± 0.12	0.75 ± 0.12	6.360	< 0.001
H-BMD	0.91 ± 0.13	0.94 ± 0.12	0.89 ± 0.13	5.441	< 0.001
T-BMD	1.10 ± 0.12	1.13 ± 0.1	1.08 ± 0.12	4.643	< 0.001
Body composition					
Total body fat (%)	31.03 ± 6.56	31.76 ± 6.25	30.69 ± 6.68	2.001	0.046

Android/gynoid ratio	1.31 ± 0.22	1.3 ± 0.22	1.31 ± 0.21	-0.107	0.915
Fat mass index (kg/m ²)	7.53 (6.20-9.09)	7.94 (6.55-9.26)	7.32 (6.17-8.99)	-2.621	0.009
Lean mass index (kg/m ²)	16.95 (15.53-18.54)	17.01 (15.45-18.66)	16.94 (15.56-18.51)	-0.952	0.341
ASMI (kg/m ²)	7.09 ± 1.17	7.23 ± 1.31	7.02 ± 1.09	2.026	0.043

¹Men aged < 50 years and women aged < 55 years.

²Men aged ≥ 50 years and postmenopausal women aged ≥ 55 years.

BMI: Body mass index; SBP: Systolic/diastolic blood pressure; DBP: Diastolic blood pressure; GNRI: Geriatric nutritional risk index; AGIs: α -glucosidase inhibitors; DPP-4Is: Dipeptidyl peptidase-4 inhibitors; SGLT-2Is: Sodium-glucose cotransporter-2 inhibitors; GLP-1RAs: Glucagon-like peptide-1 receptor agonists; Cr: Creatinine; UA: Uric acid; TG: Triglyceride; TC: Total cholesterol; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; TBil: Total bilirubin; OS: Osteocalcin; β -CTX: β -collagen special sequence; TP1NP: Total type I procollagen N-terminal extension peptide; DXA: Dual energy X-ray absorptiometry; LS-BMD: Lumbar spine (L1-L4) bone mineral density; FN-BMD: Femoral neck bone mineral density; H-BMD: Hip bone mineral density; T-BMD: Total (whole-body) bone mineral density; ASMI: Appendicular skeletal muscle index.

Table 3 Comparison of baseline characteristics among younger type 2 diabetes mellitus patients

Characteristics	Total (n = 219)	GNRI tertile 1 (n = 63)	GNRI tertile 2 (n = 68)	GNRI tertile 3 (n = 88)	<i>F</i> / <i>H</i> / χ^2	<i>P</i> value
Women [<i>n</i> (%)]	111 (50.7)	40 (63.5)	33 (48.5)	38 (43.5)	5.786	0.016
Age (yr)	43.71 ± 7.23	45.87 ± 6.84	43.04 ± 6.45	42.67 ± 7.80	6.880	0.009
Height (cm)	167.33 ± 8.55	164.57 ± 8.13	167.1 ± 8.49	169.48 ± 8.38	12.759	< 0.001
Weight (kg)	71.00 (62.00-82.00)	60.00 (56.00-66.70)	70.00 (64.00-76.85)	83.05 (74.25-93.20)	10.568	< 0.001
Diabetes duration (yr)	4.44 ± 3.82	5.84 ± 3.91	4.82 ± 4.03	3.15 ± 3.14	20.524	< 0.001
BMI (kg/m ²)	25.42 (23.11-28.34)	22.72 (21.10-23.88)	25.32 (23.84-26.57)	28.60 (26.97-31.73)	11.641	< 0.001
SBP (mmHg)	128.84 ± 13.78	126.62 ± 13.78	123.6 ± 13.08	134.49 ± 12.31	16.237	< 0.001
DBP (mmHg)	81.74 ± 10.15	80.22 ± 10.41	77.99 ± 7.75	85.72 ± 10.30	14.496	< 0.001
Hypertension [<i>n</i> (%)]	66 (30.1)	17 (27.0)	21 (30.9)	28 (31.8)	0.383	0.536
GNRI (score)	107.2 (101.18-113.56)	97.28 (92.85-99.92)	105.69 (104.20-107.71)	114.90 (112.15-120.21)	15.551	< 0.001
Glucose-lowering therapies [<i>n</i> (%)]						
Lifestyle alone	58 (26.5)	14 (22.2)	12 (17.6)	32 (36.4)	4.469	0.035
Insulin treatments	73 (33.3)	28 (44.4)	30 (44.1)	15 (17.0)	13.761	< 0.001
Insulin secretagogues	44 (20.1)	12 (19.0)	18 (26.5)	14 (15.9)	0.382	0.536
Insulin sensitizers	20 (9.1)	6 (9.5)	6 (8.8)	8 (9.1)	0.006	0.936
Metformin	92 (42.0)	20 (31.7)	31 (45.6)	41 (46.6)	2.617	0.106
AGIs	29 (13.2)	6 (9.5)	7 (10.3)	16 (18.2)	11.519	< 0.001
DPP-4Is	19 (8.7)	4 (6.3)	9 (13.2)	6 (6.8)	0.002	0.961
SGLT-2Is	26 (11.9)	11 (17.5)	8 (11.8)	7 (8.0)	3.118	0.077
GLP-1RAs	15 (6.8)	0 (0.0)	5 (7.4)	10 (11.4)	7.234	0.007
Statins	38 (17.4)	12 (19.0)	12 (17.6)	14 (15.9)	0.256	0.613
Laboratory findings						
HbA1c (%)	8.99 ± 1.9	9.58 ± 2.26	9.07 ± 1.66	8.52 ± 1.69	12.151	0.001
Albumin (g/L)	39.00 (36.8-41.6)	36.20 (34.60-37.90)	39.15 (37.20-40.75)	41.60 (39.00-44.23)	9.497	< 0.001
Cr (μ mol/L)	52.09 ± 12.75	48.4 ± 13.54	51.31 ± 10.27	55.35 ± 13.2	11.693	0.001
UA (μ mol/L)	317.68 ± 112.65	270.22 ± 140.24	313.84 ± 90.09	354.62 ± 92.24	22.682	< 0.001
TG (mmol/L)	1.99 (1.28-3.41)	1.50 (0.98-2.02)	2.03 (1.12-3.52)	2.46 (1.84-4.42)	5.412	< 0.001

TC (mmol/L)	4.5 ± 1.09	4.37 ± 0.94	4.3 ± 0.85	4.75 ± 1.30	5.389	0.021
HDL-C (mmol/L)	1.09 ± 0.25	1.15 ± 0.26	1.08 ± 0.21	1.06 ± 0.26	4.644	0.032
LDL-C (mmol/L)	2.85 ± 0.87	2.92 ± 0.91	2.86 ± 0.79	2.79 ± 0.92	0.850	0.358
TBil (μmol/L)	10.99 ± 4.28	9.78 ± 3.67	11.11 ± 4.15	11.76 ± 4.63	7.855	0.006
OS (ng/mL)	11.93 ± 3.43	12.05 ± 3.14	11.77 ± 3.07	11.98 ± 3.90	0.008	0.931
β-CTX (ng/mL)	0.47 ± 0.21	0.53 ± 0.24	0.45 ± 0.19	0.44 ± 0.20	5.436	0.021
TP1NP (ng/mL)	41.58 ± 13.84	41.95 ± 11.58	40.21 ± 13.02	42.37 ± 15.87	0.075	0.784
DXA parameters (g/cm²)						
LS-BMD	1.00 ± 0.14	0.96 ± 0.14	1.01 ± 0.13	1.02 ± 0.15	7.426	0.007
FN-BMD	0.82 ± 0.12	0.77 ± 0.11	0.82 ± 0.12	0.85 ± 0.11	18.433	< 0.001
H-BMD	0.94 ± 0.12	0.88 ± 0.11	0.94 ± 0.11	0.99 ± 0.11	34.357	< 0.001
T-BMD	1.13 ± 0.1	1.1 ± 0.11	1.12 ± 0.09	1.15 ± 0.10	8.681	0.004
Body composition						
Total body fat (%)	31.76 ± 6.25	29.85 ± 5.69	31.24 ± 5.90	33.53 ± 6.49	13.922	< 0.001
Android/gynoid ratio	1.3 ± 0.22	1.21 ± 0.22	1.31 ± 0.19	1.37 ± 0.21	22.631	< 0.001
Fat mass index (kg/m ²)	7.94 (6.55-9.26)	6.56 (5.61-7.63)	7.89 (6.52-8.88)	9.13 (7.71-11.21)	7.905	< 0.001
Lean mass index (kg/m ²)	17.01 (15.45-18.66)	15.25 (14.14-16.62)	16.93 (15.82-18.37)	18.65 (17.26-20.34)	9.380	< 0.001
ASMI (kg/m ²)	7.23 ± 1.31	6.23 ± 0.90	7.09 ± 1.00	8.04 ± 1.24	105.442	< 0.001

BMI: Body mass index; SBP: Systolic/diastolic blood pressure; DBP: Diastolic blood pressure; GNRI: Geriatric nutritional risk index; AGIs: α -glucosidase inhibitors; DPP-4Is: Dipeptidyl peptidase-4 inhibitors; SGLT-2Is: Sodium-glucose cotransporter-2 inhibitors; GLP-1RAs: Glucagon-like peptide-1 receptor agonists; Cr: Creatinine; UA: Uric acid; TG: Triglyceride; TC: Total cholesterol; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; TBil: Total bilirubin; OS: Osteocalcin; β -CTX: β -collagen special sequence; TP1NP: Total type I procollagen N-terminal extension peptide; DXA: Dual energy X-ray absorptiometry; LS-BMD: Lumbar spine (L1-L4) bone mineral density; FN-BMD: Femoral neck bone mineral density; H-BMD: Hip bone mineral density; T-BMD: Total (whole-body) bone mineral density; ASMI: Appendicular skeletal muscle index.

Table 4 Comparison of baseline characteristics among older type 2 diabetes mellitus patients

Characteristics	Total (n = 470)	GNRI tertile 1 (n = 167)	GNRI tertile 2 (n = 162)	GNRI tertile 3 (n = 141)	F/H/ χ^2	P value
Women [n (%)]	184 (39.1)	69 (41.3)	63 (38.9)	52 (36.9)	0.636	0.425
Age (yr)	61.12 ± 7.25	62.6 ± 7.56	61.43 ± 7.01	59.02 ± 6.70	18.962	< 0.001
Height (cm)	166.69 ± 8.1	165.5 ± 7.80	167.1 ± 8.55	167.62 ± 7.79	5.425	0.020
Weight (kg)	70.00 (62.00-80.00)	62.00 (57.00-70.00)	72.50 (65.00-80.00)	80.00 (72.00-85.50)	12.768	< 0.001
Diabetes duration (yr)	8.68 ± 6.62	10.13 ± 6.79	8.74 ± 6.90	6.89 ± 5.62	18.945	< 0.001
BMI (kg/m ²)	25.39 (23.32-27.55)	23.05 (21.34-24.57)	25.71 (24.33-27.11)	28.01 (26.51-29.75)	15.296	< 0.001
SBP (mmHg)	136.16 ± 15.49	135.35 ± 17.25	138.2 ± 15.13	134.78 ± 13.42	0.049	0.825
DBP (mmHg)	80.65 ± 9.75	79.15 ± 10.12	81.93 ± 9.93	80.96 ± 8.86	2.998	0.084
Hypertension [n (%)]	267 (56.8)	95 (56.9)	96 (59.3)	76 (53.9)	0.237	0.626
GNRI (score)	105.09 (98.93-110.98)	97.09 (93.08-99.55)	105.57 (103.59-107.63)	113.94 (111.77-118.57)	22.930	< 0.001
Glucose-lowering therapies [n (%)]						
Lifestyle alone	63 (13.4)	17 (10.2)	24 (14.8)	22 (15.6)	2.019	0.155
Insulin treatments	175 (37.2)	74 (44.3)	59 (36.4)	42 (29.8)	6.938	0.008
Insulin secretagogues	178 (37.9)	71 (42.5)	60 (37.0)	47 (33.3)	2.771	0.096
Insulin sensitizers	59 (12.6)	19 (11.4)	22 (13.6)	18 (12.8)	0.152	0.697

Metformin	230 (48.9)	68 (40.7)	79 (48.8)	83 (58.9)	10.012	0.002
AGIs	76 (16.2)	17 (10.2)	26 (16.0)	33 (23.4)	9.802	0.002
DPP-4Is	38 (8.1)	14 (8.4)	14 (8.6)	10 (7.1)	0.158	0.691
SGLT-2Is	67 (14.3)	17 (10.2)	27 (16.7)	23 (16.3)	2.509	0.113
GLP-1RAs	26 (5.5)	3 (1.8)	9 (5.6)	14 (9.9)	9.636	0.002
Statins	84 (17.9)	25 (15.0)	33 (20.4)	26 (18.4)	0.707	0.400
Laboratory findings						
HbA1c (%)	8.98 ± 1.82	9.47 ± 1.93	8.86 ± 1.61	8.54 ± 1.79	21.198	< 0.001
Albumin (g/L)	38.25 (35.8-41)	35.80 (33.50-37.30)	38.40 (36.70-40.60)	41.70 (39.70-44.00)	15.071	< 0.001
Cr (μmol/L)	61.5 ± 23.74	61.93 ± 27.54	60.59 ± 24.35	62.03 ± 17.46	0.000	0.994
UA (μmol/L)	310.35 ± 92.39	282.96 ± 85.27	314.1 ± 89.47	338.47 ± 95.18	29.509	< 0.001
TG (mmol/L)	1.78 (1.15-2.87)	1.42 (0.97-2.44)	1.75 (1.18-2.62)	2.29 (1.41-3.83)	5.347	< 0.001
TC (mmol/L)	4.37 ± 1.04	4.27 ± 1.04	4.34 ± 1.03	4.53 ± 1.04	4.991	0.026
HDL-C (mmol/L)	1.16 ± 0.27	1.15 ± 0.29	1.18 ± 0.26	1.13 ± 0.27	0.348	0.555
LDL-C (mmol/L)	2.79 ± 0.87	2.75 ± 0.87	2.77 ± 0.84	2.87 ± 0.9	1.525	0.218
TBil (μmol/L)	11.31 ± 4.89	10.43 ± 4.91	11.56 ± 4.89	12.06 ± 4.75	8.890	0.003
OS (ng/mL)	11.81 ± 4.23	12.07 ± 4.63	11.93 ± 4.19	11.37 ± 3.76	1.992	0.159
β-CTX (ng/mL)	0.45 ± 0.23	0.5 ± 0.25	0.44 ± 0.22	0.39 ± 0.18	22.076	< 0.001
TP1NP (ng/mL)	40.34 ± 14.84	40.65 ± 14.83	40.96 ± 15.33	39.26 ± 14.33	0.617	0.433
DXA parameters (g/cm²)						
LS-BMD	0.95 ± 0.16	0.91 ± 0.15	0.98 ± 0.18	0.97 ± 0.14	12.015	0.001
FN-BMD	0.75 ± 0.12	0.71 ± 0.11	0.77 ± 0.13	0.78 ± 0.10	29.138	< 0.001
H-BMD	0.89 ± 0.13	0.84 ± 0.12	0.9 ± 0.14	0.93 ± 0.11	45.242	< 0.001
T-BMD	1.08 ± 0.12	1.06 ± 0.12	1.09 ± 0.13	1.1 ± 0.11	10.818	0.001
Body composition						
Total body fat (%)	30.69 ± 6.68	28.72 ± 6.83	30.62 ± 5.81	33.09 ± 6.71	34.740	< 0.001
Android/gynoid ratio	1.31 ± 0.21	1.24 ± 0.22	1.33 ± 0.21	1.36 ± 0.19	28.386	< 0.001
Fat mass index (kg/m ²)	7.32 (6.17-8.99)	6.26 (4.97-7.51)	7.38 (6.42-8.59)	8.70 (7.20-10.56)	10.212	< 0.001
Lean mass index (kg/m ²)	16.94 (15.56-18.51)	15.82 (14.71-17.03)	17.17 (15.92-18.43)	18.56 (16.77-19.81)	10.488	< 0.001
ASMI (kg/m ²)	7.02 ± 1.09	6.44 ± 0.91	7.09 ± 0.97	7.63 ± 1.08	112.733	< 0.001

BMI: Body mass index; SBP: Systolic/diastolic blood pressure; DBP: Diastolic blood pressure; GNRI: Geriatric nutritional risk index; AGIs: α -glucosidase inhibitors; DPP-4Is: Dipeptidyl peptidase-4 inhibitors; SGLT-2Is: Sodium-glucose cotransporter-2 inhibitors; GLP-1RAs: Glucagon-like peptide-1 receptor agonists; Cr: Creatinine; UA: Uric acid; TG: Triglyceride; TC: Total cholesterol; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; TBil: Total bilirubin; OS: Osteocalcin; β -CTX: β -collagen special sequence; TP1NP: Total type I procollagen N-terminal extension peptide; DXA: Dual energy X-ray absorptiometry; LS-BMD: Lumbar spine (L1-L4) bone mineral density; FN-BMD: Femoral neck bone mineral density; H-BMD: Hip bone mineral density; T-BMD: Total (whole-body) bone mineral density; ASMI: Appendicular skeletal muscle index.

Table 5 Multiple linear regression models displaying associations of the Geriatric Nutritional Risk Index with bone mineral density

Models	B (95%CI)	β	t value	P value	Adjusted R ² for model
Lumbar spine BMD					
Model 0 ¹	0.003 (0.002 to 0.004)	0.186	4.952	< 0.001	0.033
Model 1 ²	-0.002 (-0.004 to 0.000)	-0.113	-1.919	0.055	0.150
Model 2 ³	-0.002 (-0.004 to 0.000)	-0.105	-1.765	0.078	0.153

Model 3 ⁴	0.040 (0.008 to 0.071)	2.402	2.492	0.013	0.197
Femoral neck BMD					
Model 0 ¹	0.004 (0.003 to 0.005)	0.281	7.664	< 0.001	0.077
Model 1 ²	-0.001 (-0.002 to 0.000)	-0.071	-1.32	0.187	0.293
Model 2 ³	-0.001 (-0.002 to 0.000)	-0.06	-1.12	0.263	0.306
Model 3 ⁴	0.027 (0.004 to 0.049)	2.047	2.345	0.019	0.341
Total hip BMD					
Model 0 ¹	0.005 (0.004 to 0.006)	0.363	10.213	< 0.001	0.131
Model 1 ²	0.000 (-0.002 to 0.001)	-0.034	-0.636	0.525	0.312
Model 2 ³	0.000 (-0.002 to 0.001)	-0.025	-0.477	0.634	0.318
Model 3 ⁴	0.021 (-0.003 to 0.044)	1.52	1.745	0.082	0.343

¹Unadjusted model.

²Adjusted for age, sex, diabetes duration, hypertension, SBP, DBP, and BMI.

³Additionally adjusted for antidiabetic treatments and statin medications.

⁴Additionally adjusted for HbA1c, Osteocalcin, β -collagen special sequence, total type I procollagen N-terminal extension peptide, albumin, Creatinine, uric acid, triglyceride, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, total bilirubin.

95%CI: 95% confidence interval; BMD: Bone mineral density.

Table 6 Determinants of bone mineral density using multivariate forward linear regression analysis

Factors	B	SE	t value	P value	95%CI	
					Lower	Upper
Lumbar spine BMD						
Age	-0.002	0.001	-3.754	< 0.001	-0.003	-0.001
Height	0.003	0.001	3.669	< 0.001	0.001	0.005
Diabetes duration	-0.003	0.001	-2.665	0.008	-0.005	-0.001
Albumin	-0.004	0.001	-2.864	0.004	-0.007	-0.001
Cr	0.001	0.000	1.983	0.048	0.000	0.001
β-CTX	-0.089	0.033	-2.724	0.007	-0.153	-0.025
TP1NP	-0.001	0.000	-1.633	0.103	-0.002	0.000
ASMI	-0.040	0.016	-2.449	0.015	-0.072	-0.008
Lean mass index	0.036	0.008	4.498	< 0.001	0.020	0.051
Femoral neck BMD						
Age	-0.003	0	-6.8	< 0.001	-0.003	-0.002
Height	0.003	0.001	4.672	< 0.001	0.002	0.004
Diabetes duration	-0.002	0.001	-3.617	< 0.001	-0.004	-0.001
Albumin	-0.003	0.001	-2.698	0.007	-0.005	-0.001
β-CTX	-0.100	0.018	-5.589	< 0.001	-0.135	-0.065
Android/gynoid ratio	-0.045	0.02	-2.259	0.024	-0.084	-0.006
ASMI	0.011	0.012	0.963	0.336	-0.012	0.034
Lean mass index	0.014	0.006	2.457	0.014	0.003	0.025
Total hip BMD						
Age	-0.002	0.000	-5.451	< 0.001	-0.003	-0.001
Weight	0.002	0.001	3.142	0.002	0.001	0.003
Diabetes duration	-0.002	0.001	-3.327	0.001	-0.004	-0.001

β -CTX	-0.082	0.019	-4.403	< 0.001	-0.118	-0.045
Android/gynoid ratio	-0.041	0.02	-2.003	0.046	-0.081	-0.001
Lean mass index	0.020	0.003	6.266	< 0.001	0.014	0.026

95%CI: 95% confidence interval; BMD: Bone mineral density; Cr: Creatinine; β -CTX: β -collagen special sequence; TP1NP: Total type I procollagen N-terminal extension peptide; ASMI: Appendicular skeletal muscle index.

Table 7 Determinants of appendicular skeletal muscle index using multivariate forward linear regression analysis

Factors	B	SE	t value	P value	95%CI	
					Lower	Upper
Men						
Age	-0.012	0.003	-3.721	< 0.001	-0.019	-0.006
Weight	0.019	0.006	2.983	0.003	0.006	0.031
Diabetes duration	-0.014	0.005	-2.587	0.010	-0.025	-0.003
BMI	0.136	0.022	6.238	< 0.001	0.093	0.178
HbA1c	-0.057	0.017	-3.449	0.001	-0.090	-0.025
Women						
Age	-0.008	0.003	-2.811	0.005	-0.014	-0.003
Weight	0.066	0.003	20.846	< 0.001	0.059	0.072
Height	-0.030	0.007	-4.491	< 0.001	-0.043	-0.017
TBil	-0.017	0.007	-2.369	0.018	-0.032	-0.003
OS	0.019	0.009	2.147	0.033	0.002	0.037
β-CTX	-0.536	0.175	-3.059	0.002	-0.881	-0.191

95%CI: 95% confidence interval; BMI: Body mass index; TBil: Total bilirubin; OS: Osteocalcin; β -CTX: β -collagen special sequence.

an increased risk of low muscle mass *via* a variety of mechanisms. The main causes include insulin resistance, inflammation, and the production of glycation end products. Therefore, nutritional balance is beneficial to control blood sugar and reduce the incidence of sarcopenia. Individuals with type 2 diabetes, especially the elderly, need individualized dietary strategies to reduce the incidence of malnutrition. Regular nutritional assessments are necessary. People with type 2 diabetes can avoid the adverse effects of malnutrition by adjusting their diet.

At all bone sites, there was a correlation between low BMD and a high level of β -CTX, which is the third significant discovery of this research. β -CTX is derived from the degradation of type I collagen, and its content in bone collagen is much higher than that in the rest of the tissue, so it can be more representative and more directly reflect the degradation of bone matrix collagen and be used as an indicator of bone resorption. Bone homeostasis depends on the resorption and formation of bones. Long-term hyperglycemia can affect the adhesion of osteoblasts to collagen, causing dysfunction of osteoblasts, inhibiting bone formation and accelerating bone resorption, causing an increase in PINP and β -CTX. This may explain our finding of an association between a high β -CTX level and low BMD. β -CTX plays a critical role in bone turnover and is a sensitive marker for the early diagnosis of osteoporosis.

Another important finding of this study is that age was negatively correlated with ASMI. Sarcopenia is the age-related loss of muscle mass, strength, and function[28]. Degenerative changes in the structure and function of the human neuromuscular system occur with age, and the presence of diabetes accelerates the decline in muscle mass and strength through changes such as high levels of reactive oxygen species produced by oxidative stress and dysfunctional mitochondria. In this study, we also found a significant association between weight and ASMI. The majority of studies have shown that low BMI is also associated with sarcopenia[29]. Malnutrition, a potent risk factor for sarcopenia, could potentially account for the higher occurrence and frequency of sarcopenia in individuals with reduced body weight. Malnutrition, a potent risk factor for sarcopenia, might well explain the increased prevalence and incidence of sarcopenia in individuals with lower weight.

This study had multiple limitations. Because the study had a cross-sectional design, it was not possible to establish causal relationships. Furthermore, the participants chosen for this research encompassed both males and females spanning a wide age bracket of 21 to 81 years. T2DM patients of the same gender and age range have not been studied, but this study is closer to the clinical situation. Also, we only included participants who were hospitalized; we did not evaluate muscle strength and quality. In the end, although we did not consider that environmental pollutants (mainly air

pollutants) is able to significantly affect both the clinical features of T2DM (mainly onset of disease and blood sugar control) and the nutritional status, we selected participants who lived in the same area for a long time. In the future, we will consider selecting participants from different regions of China for further research.

CONCLUSION

Poor nutrition, as indicated by a low GNRI, was associated with low levels of ASMI and BMD at all bone sites in T2DM patients. Using the GNRI to evaluate nutritional status and using DXA to investigate body composition in patients with T2DM is of value in assessing bone health and physical performance.

ARTICLE HIGHLIGHTS

Research background

In people with type 2 diabetes mellitus (T2DM), the association between nutrition, sarcopenia, and osteoporosis has rarely been explored.

Research motivation

The relationship between nutritional status and bone mass has been observed in different populations, including individuals with chronic obstructive pulmonary disease, rheumatoid arthritis, and end-stage renal disease.

Research objectives

Assess the associations among nutrition, bone mineral density (BMD) and body composition in patients with T2DM.

Research methods

A total of 689 patients with T2DM were included to perform a retrospective analysis. The general information and biochemical indices of these patients were statistically analyzed.

Research results

Those who had a high Geriatric Nutritional Risk Index (GNRI) tended to be younger and had lower HbA1c, higher BMD at all bone sites, and higher appendicular skeletal muscle index.

Research conclusions

Poor nutrition, as indicated by a low GNRI, was associated with low levels of ASMI and BMD at all bone sites in type 2 diabetes mellitus patients.

Research perspectives

We used a retrospective study to explore the association between nutrition, sarcopenia, and osteoporosis in patients with T2DM.

FOOTNOTES

Author contributions: Zhu XX and Wang LH designed the research; Zhu XX and Yao KF collected the data; Zhu XX and Huang HY analyzed the data; Zhu XX and Yao KF wrote the paper; Wang LH reviewed the paper.

Supported by Social Development Projects of Nantong, No. MS22021008 and No. QNZ2022005.

Institutional review board statement: The study was approved by the institutional review board of The Second Affiliated Hospital of Nantong University, First People's Hospital of Nantong City (approval number: 2021KT063).

Informed consent statement: All study participants, or their legal guardian, provided informed written consent prior to study enrollment.

Conflict-of-interest statement: All the Authors have no conflict of interest related to the manuscript.

Data sharing statement: No additional data are available.

STROBE statement: The authors have read the STROBE Statement—checklist of items, and the manuscript was prepared and revised according to the STROBE Statement—checklist of items.

Open-Access: This article is an open-access article that was selected by an in-house editor and fully peer-reviewed by external reviewers.

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Country/Territory of origin: China

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S-Editor: Lin C

L-Editor: A

P-Editor: Yuan YY

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