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Predictive efficacy of different diagnostic criteria for sarcopenia in osteoporosis and fractures

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This study aims to compare the predictive efficacy of different diagnostic criteria for sarcopenia in forecasting the occurrence of osteoporosis (OP) and fractures. Utilizing data from the Global Health Data Exchange, the burden of musculoskeletal disorders (MSDs) was assessed through indicators including incidence, prevalence, and disability-adjusted life years. Trends in MSD burden were analyzed using the Joinpoint regression model to calculate the average annual percentage change. A retrospective cohort study was conducted on clinical data from 8180 patients who received care at the Endocrinology Department of the First Affiliated Hospital of Fujian Medical University between April 2008 and June 2024. Patients were categorized into four groups based on sarcopenia diagnostic criteria established by the European Working Group on Sarcopenia in Older People (EWGSOP), the International Working Group on Sarcopenia (IWGS), the Asian Working Group on Sarcopenia 2019 (AWGS 2019), and the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project. We compared demographic data, chronic disease history, body composition, bone mineral density, FRAX fracture risk, and the incidence of osteoporosis to evaluate the predictive validity of each diagnostic criterion for osteoporosis and fracture risk in patients with sarcopenia. (1) The prevalence of sarcopenia, as defined by the IWGS, FNIH, EWGSOP, and AWGS 2019 diagnostic criteria, was 39.2%, 28.3%, 55.0%, and 30.1%, respectively. (2) After adjusting for age, gender, and body mass index (BMI), a significant association between osteoporosis and sarcopenia was observed across all four diagnostic criteria (all $P < 0.05$). Furthermore, sarcopenia, as determined by the EWGSOP and AWGS 2019 criteria, was associated with a moderate-to-high risk of major osteoporotic fractures and hip fractures within the next 10 years ($P < 0.05$). (3) Spearman's correlation coefficients for sarcopenia with Procollagen type I N-terminal propeptide (PINP), appendicular lean mass (ALM), ALM/height squared (Ht^2), and ALM/BMI were − 0.034, − 0.308, − 0.261, and − 0.252, respectively. PINP, ALM, ALM/Ht^2, and ALM/BMI were identified as significant factors influencing osteoporosis, with odds ratios of 0.996, 0.765, 0.535, and 0.010, respectively. The burden of MSDs is increasing in China and globally, driven primarily by population aging. Sarcopenia is significantly associated with osteoporosis and a moderate-to-high risk of fracture when diagnosed using the FNIH and EWGSOP criteria. PINP and ALM are protective factors against osteoporosis development in patients with sarcopenia.

Keywords Osteoporosis, Sarcopenia, Diagnostic criteria, Global burden of disease, Musculoskeletal disorders

Musculoskeletal disorders (MSDs) encompass a spectrum of conditions affecting the muscles, bones, joints, and associated locomotor systems, with the lumbar spine, cervical spine, and limbs being the most commonly affected sites. These disorders are typically characterized by persistent pain, often accompanied by muscle

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stiffness, reduced mobility, and impaired daily function. MSDs include a broad range of conditions, such as osteoarthritis, rheumatoid arthritis, gout, osteoporosis (OP), fragility fractures, and sarcopenia[1–3]. In 2017, the global incidence of MSDs reached 334 million cases, with China alone reporting approximately 51 million new cases. With the progressive aging of the population and increasing life expectancy, MSDs have become a leading cause of years lived with disability[4,5]. MSDs, often perceived as nonfatal and irreversible conditions associated with aging, have yet to attract widespread attention despite their significant disease burden[2,6]. OP is a well-defined metabolic bone disease characterized by decreased bone mass, altered microarchitectural integrity, and increased bone fragility, resulting in a substantially heightened risk of fractures. Sarcopenia, by contrast, is primarily characterized by the loss of muscle mass, strength, and function, though its diagnostic criteria remain heterogeneous across different guidelines. The European Working Group on Sarcopenia in Older People (EWGSOP2) and the Asian Working Group on Sarcopenia (AWGS) offer relatively comprehensive and accurate diagnostic frameworks but necessitate specialized equipment and expertise. The International Working Group on Sarcopenia (IWGS) criteria are simpler and more accessible but do not account for muscle strength. While widely adopted, the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project criteria may require population-specific adjustments in cut-off values to enhance diagnostic precision across diverse ethnic groups.

Emerging evidence indicates that sarcopenia and OP share several pathophysiological mechanisms, including common regulatory pathways that govern muscle and bone homeostasis. These tissues originate from mesenchymal stem cells located between the endoderm and ectoderm and subsequently undergo differentiation to form the musculoskeletal system[7,8]. Anatomically adjacent, muscle and bone interact through mechanical loading and biochemical signaling[9], with sarcopenia frequently coexisting with OP[10]. Both conditions are prevalent among the elderly and are associated with an elevated risk of adverse outcomes, such as falls, fractures, cardiovascular and cerebrovascular events, and mortality. These disorders significantly impact the quality of life and contribute to the socioeconomic burden in aging populations. With the global population aging and the incidence of sarcopenia and OP rising, the interplay between these conditions has attracted growing attention from researchers worldwide.

As the world's most populous developing country, China comprises approximately one-fifth of the global population. The proportion of older adults in China continues to increase, and consequently, the prevalence of sarcopenia and OP is expected to rise further[11–13]. Identifying diagnostic criteria for sarcopenia that can reliably predict OP and fracture risk is, therefore, of critical clinical importance for the early diagnosis and concurrent management of these conditions.

Materials and methods

Background of the study-global burden of disease (GBD) of MSDs.

Data sources of information on GBD

Data on the burden of MSDs in China from 1990 to 2021 were obtained from the Global Health Data Exchange (GHDx), a repository developed as part of the GBD study initiated by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington, United States. The most recent dataset was released in 2021. The extracted data included the number of patients, incidence rates, disability-adjusted life years (DALYs), and standardized DALY rates attributable to specific risk factors[14,15].

Statistical methods

Age–period–cohort model fitting was performed using the Epi package (version 2.46) in *R* software (version 4.3.1). Trends in the disease burden attributable to MSDs were assessed using the Joinpoint regression model (version 4.9.0). The average annual percentage change (AAPC) and corresponding 95% confidence intervals (CIs) were calculated to evaluate changes in the incidence and burden of MSDs, along with their associated risk factors, from 1990 to 2021. A P value of < 0.05 was considered to indicate statistical significance.

Clinical study—Correlation between sarcopenia and OP with different diagnostic criteria.

Study population

The study population consisted of 8180 patients who underwent physical examinations or were hospitalized in the Department of Endocrinology at the First Affiliated Hospital of Fujian Medical University between April 2008 and June 2024. The median age of the participants was 63 years, with 4068 males and 4112 females. Patient demographic and clinical data were retrieved from the hospital's outpatient and inpatient case systems. The collected information included age, height, height squared (Ht^2), gender, weight, systolic blood pressure (SBP), diastolic blood pressure (DBP), laboratory parameters, body mass index (BMI), history of diabetes mellitus, history of fractures, smoking status, body composition, and bone mineral density (BMD). All patients provided written informed consent prior to participation.

Inclusion criteria for this study

(1) Patients were examined or hospitalized at the First Affiliated Hospital of Fujian Medical University between April 2008 and June 2024, with all relevant examinations completed during this period; (2) Male participants aged 50 years or older and postmenopausal female participants; (3) Individuals capable of self-care in daily life with normal mobility.

Exclusion criteria

(1) Presence of congenital malformations or genetic diseases; (2) History of receiving radiation therapy; (3) Abnormal liver or kidney function test results; (4) Use of medications affecting muscle or bone metabolism

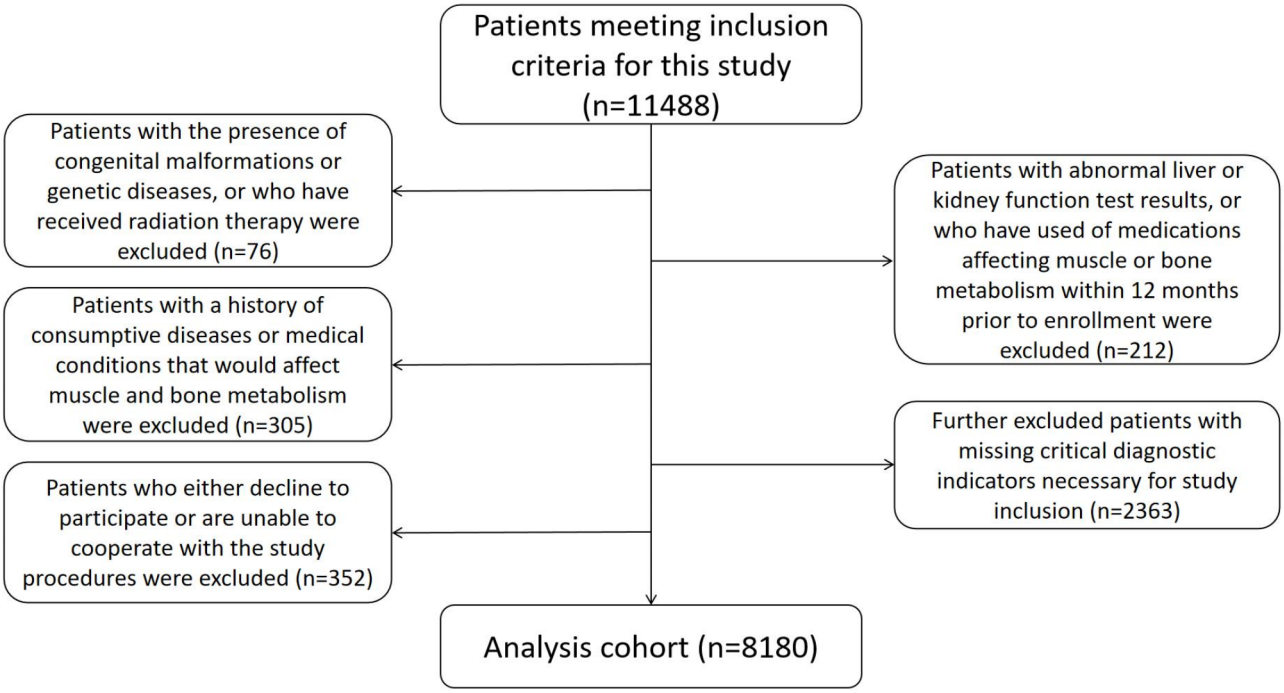

Fig. 1. Flow chart.

Parameter	IWGS	FNIH	EWGSOP	AWGS 2019
Gait speed	< 1.0 m/s	≤ 0.8 m/s	≤ 0.8 m/s	< 1.0 m/s
Muscle mass	Male: ALM/Ht^2 ≤ 7.23 kg/m^2, Female: ALM/Ht^2 ≤ 5.67 kg/m^2	Male: ALM/BMI < 0.789, Female: ALM/BMI < 0.512	Male: ALM < 20 kg or ALM/Ht^2 < 7.0 kg/m^2, Female: ALM < 15 kg or ALM/Ht^2 < 5.5 kg/m^2	Male: ALM/Ht^2 < 7.0 kg/m^2, Female: ALM/Ht^2 < 5.4 kg/m^2
Muscle strength	\	Male: < 26 kg, Female: < 16 kg	Male: < 27 kg, Female: < 16 kg	Male: < 28 kg, Female: < 18 kg
Operational definition	Performance↓ + muscle↓	Performance↓ + strength↓ or muscle↓	Strength↓ + muscle↓ + Performance (for severity)↓	Strength↓ or performance↓ + muscle↓

Table 1. Four diagnostic criteria for sarcopenia (IWGS, FNIH, EWGSOP, and AWGS 2019). *ALM* appendicular lean mass, *Ht* height, *BMI* body mass index.

(e.g., corticosteroids, sex hormones, bisphosphonates) within 12 months prior to enrollment; (5) History of medical conditions known to affect muscle and bone metabolism, including coronary artery disease, chronic obstructive pulmonary disease (COPD), hyperthyroidism, hyperparathyroidism, renal insufficiency, or gastrointestinal diseases; (6) Presence of consumptive diseases such as malignancies or tuberculosis; (7) Missing critical diagnostic indicators necessary for study inclusion; and (8) Patients who either decline to participate or are unable to cooperate with the study procedures (Fig. 1).

Research methodology

Diagnosis of OP

(1) According to the World Health Organization's (WHO) diagnostic criteria for osteoporosis (OP), bone mineral density (BMD) is measured using DXA scanning. The T-scores obtained categorize BMD into three levels: normal BMD (T-score ≥ − 1.0 SD), osteopenia (T-score between − 1.0 SD and − 2.5 SD), and OP (T-score ≤ − 2.5 SD)[16,17].

(2) Diagnostic criteria based on fragility fractures serve as another vital method for diagnosing osteoporosis: fractures that occur due to increased bone fragility when subjected to normal or mild external forces are also indicative of osteoporosis. Common sites include the vertebral bodies, hip, distal radius, proximal humerus, and pelvis[18].

Diagnosis of sarcopenia

Sarcopenia was diagnosed according to the criteria established by four major working groups: the EWGSOP[19], the IWGS[20], the AWGS 2019[21], and the FNIH[22]. Patients were categorized into four corresponding groups based on the diagnostic rules outlined in Table 1.

Collection of body composition, BMD, and general information
All participants underwent dual-energy X-ray absorptiometry (DXA) scanning in a temperature-controlled environment while at rest. BMD measurements were obtained from the lumbar vertebrae (L1, L2, L3, L4, and L1–4), femoral neck, and total hip. All scans were performed by an experienced imaging physician following standardized protocols. All patients' general information was retrieved from the hospital's electronic medical record system.

Statistical processing
All statistical analyses were performed using SPSS software (version 25.0). Variables were tested for normality prior to analysis. Normally distributed variables were presented as mean ± standard deviation (SD), while non-normally distributed variables were reported as medians with interquartile ranges [M (P25, P75)]. Categorical variables were expressed as counts and percentages [n (%)]. Comparisons between two groups of normally distributed variables were performed using the independent-samples t-test. The Wilcoxon rank-sum test was employed for non-normally distributed variables. Differences in categorical variables between groups were analyzed using the chi-square test. Logistic regression models were constructed to calculate the odds ratio (OR) and corresponding 95% CI to evaluate the predictive value of different sarcopenia diagnostic criteria for osteoporosis. A two-tailed *P* value of less than 0.05 was considered statistically significant.

Results

Trends in MSDs in China and globally

The incidence of MSDs in China increased from 42,000,767 (95% CI 37,804,103–46,495,427) in 1990 to 68,646,958 (95% CI 61,976,491–74,990,168) in 2021, reflecting a cumulative increase of 63.44%. Globally, the number of MSD cases rose from 215,339,150 (95% CI 194,696,724–237,685,150) in 1990 to 367,193,431 cases (95% CI 33,3085,118–402,083,085) in 2021, marking a cumulative increase of 70.52%. In 2021, MSDs were associated with 118,499 deaths worldwide (95% CI 103,131–128,548), representing a 102.98% increase compared with 1990. In China, the mortality rate attributable to MSDs increased by 93.38% from 1990 to 2021. The prevalence of MSDs in China surged from 170,594,404 (95% CI 159,481,066–182,116,267) in 1990 to 342,123,786 (95% CI 322,541,900–361,025,855) in 2021, with a cumulative increase of 100.55%.

Globally, the prevalence of MSDs increased from 865,073,986 cases (95% CI 813,102,876–917,749,058) in 1990 to 1,686,561,517 cases (95% CI 1,599,166,937–1,780,146,354) in 2021, representing a cumulative increase of 94.96%. Over the same period, the global age-standardized prevalence rate (ASPR) rose from 19,178.471 per 100,000 individuals (95% CI 18,084.374–20,279.512) in 1990 to 19,832.199 per 100,000 people (95% CI 18,810.813–20,938.74) in 2021. In China, the ASPR increased from 16,966.24 per 100,000 individuals (95% CI 15,950.233–17,975.765) in 1990 to 17,403.523 per 100,000 individuals (95% CI 16,414.427–18,413.976) in 2021. The AAPC in MSD prevalence from 1990 to 2021 was 0.0925% (95% CI 0.0725–0.1125) in China, while the global AAPC during the same period was 0.1076% (95% CI 0.0894–0.1259) (Table 2).

The burden of MSDs across different age groups in China (1990 vs. 2021)

Figure 2 shows the incidence and prevalence of MSDs across different age groups of men and women in China in 1990 and 2021. MSD prevalence increased with age, with a notable rise in the overall disease burden in both sexes in 2021 compared with 1990, and the peaks of MSDs prevalence in occurred both men and women within the 55–59-year age group in both 1990 and 2021. Moreover, females consistently outnumbered males in nearly

Location	Measure	1990		2021		1990–2021 AAPC
		All-ages cases	Age-standardized rates per 100,000 people	All-ages cases	Age-standardized rates per 100,000 people	
		n (95% CI)	n (95% CI)	n (95% CI)	n (95% CI)	n (95% CI)
China	Incidence	42,000,767 (37,804,103–46,495,427)	4039.135 (3648.559–4437.889)	68,646,958 (61,976,491–74,990,168)	3629.612 (3307.358–3954.468)	− 0.3427 (− 0.3814 to − 0.304)
	Prevalence	170,594,404 (159,481,066–182,116,267)	16,966.24 (15,950.233–17,975.765)	342,123,786 (322,541,900–361,025,855)	17,403.523 (16,414.427–18,413.976)	0.0925 (0.0725–0.1125)
	Deaths	10,056 (8354–12,213)	1.217 (1–1.489)	19,446 (15,146–24,480)	1.082 (0.838–1.355)	− 0.6888 (− 0.9367 to − 0.4402)
	DALYs	16,629,496 (12,164,722–22,138,075)	1615.732 (1169.69–2151.245)	30,419,426 (21,752,735–41,618,819)	1578.368 (1140.056–2129.434)	− 0.0614 (− 0.1045 to − 0.0183)
Global	Incidence	215,339,150 (194,696,724–237,685,150)	4641.497 (4195.958–5099.977)	367,193,431 (333,085,118–402,083,085)	4351.794 (3962.305–4762.68)	− 0.2091 (− 0.222 to − 0.1963)
	Prevalence	865,073,986 (813,102,876–917,749,058)	19,178.471 (18,084.374–20,279.512)	1,686,561,517 (1,599,166,937–1,780,146,354)	19,832.199 (18,810.813–20,938.74)	0.1076 (0.0894–0.1259)
	Deaths	58,380 (52,987–62,644)	1.551 (1.406–1.664)	118,499 (103,131–128,548)	1.439 (1.255–1.562)	− 0.1577 (− 0.3447 to 0.0296)
	DALYs	86,285,114 (63,579,335–114,732,382)	1886.226 (1379.635–2523.283)	161,877,699 (118,018,720–216,145,508)	1908.871 (1394.971–2547.503)	0.0371 (0.0169–0.0573)

Table 2. All-age case and age-labeled incidence, prevalence, mortality, and DALYs rates for MSDs in China and globally in 1990 and 2021, and corresponding AAPC values.

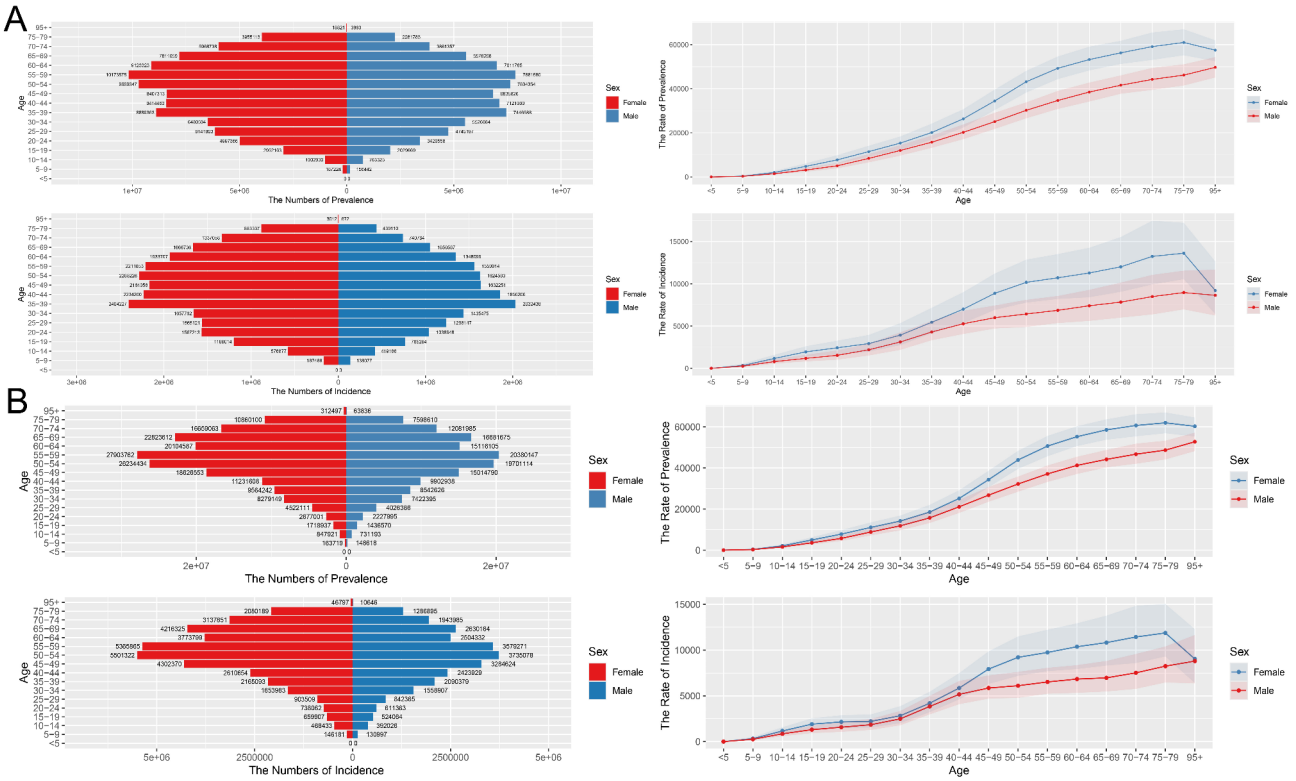

Fig. 2. (**A**) Includes bilateral and line graphs comparing the incidence and prevalence of MSDs in different age groups of men and women in China in 1990. (**B**) Bilateral and line graphs comparing the incidence and prevalence of MSDs among men and women of different age groups in China in 2021.

every age group. The incidence of MSDs increases with age. Notably, the peak prevalence in 2021 was delayed in both genders compared to 1990, with females continuing to exhibit higher rates than males across all age groups. The disparity in prevalence rates between females and males widened significantly after the age of 45–49 years.

Factors affecting the changes in MSD incidence

In both male and female populations, the aging of the population structure and population growth have contributed to the incidence of MSDs, while epidemiological trends have had an inhibitory effect. Moreover, the aging of the population structure has played the most significant role in the increase in MSD incidence (Fig. 3).

Clinical characteristics of study participants

A total of 8180 study subjects were included in this study, comprising 4068 men and 4112 women. Among the participants, 2145 were non-diabetic, and 6035 had diabetes. Table 3 shows no statistically significant differences between the diabetic and non-diabetic groups regarding sex, appendicular lean mass (ALM), ALM/BMI, and body weight. However, the diabetic group demonstrated significantly higher values for age, BMI, probability of major osteoporotic fracture (PMOF) within the next 10 years, probability of hip fracture (PHF) within the next 10 years, SBP, DBP, ALM/Ht^2 and the proportion of patients with osteoporosis (P value < 0.05).

Prevalence of sarcopenia according to four different criteria

As shown in Fig. 4, the prevalence of sarcopenia varied depending on the diagnostic criteria applied. For instance, IWGS criteria revealed 39.2% overall (37.6% in the diabetic group and 43.4% in the non-diabetic group; $P < 0.01$). FNIH criteria revealed 28.3% overall (26.0% in the diabetic group and 34.5% in the non-diabetic group; $P < 0.01$). EWGSOP criteria revealed 55.0% overall (56.3% in the diabetic group and 51.3% in the non-diabetic group; $P < 0.01$), while AWGS 2019 criteria: 30.1% overall (27.5% in the diabetic group and 37.6% in the non-diabetic group; $P < 0.01$).

Correlation between sarcopenia adjudicated by four criteria and PMOF, PHF, and osteoporosis (uncorrected)

As depicted in Table 4, the relationship between sarcopenia and PMOF, PHF, and osteoporosis in diabetic patients was evaluated using four different diagnostic criteria. The uncorrected logistic regression analysis yielded the initial findings. As determined by the IWGS criteria, Sarcopenia was significantly associated with an increased risk of osteoporosis (OR 1.486; 95% CI 1.304–1.694; $P < 0.001$). Sarcopenia, as determined by the EWGSOP criteria, was associated with a significantly increased risk of osteoporosis (OR 2.893; 95% CI 2.497–3.351; $P < 0.001$), as well as significantly elevated PMOF (OR 4.393; 95% CI 1.944–9.929; $P < 0.001$) and PHF (OR

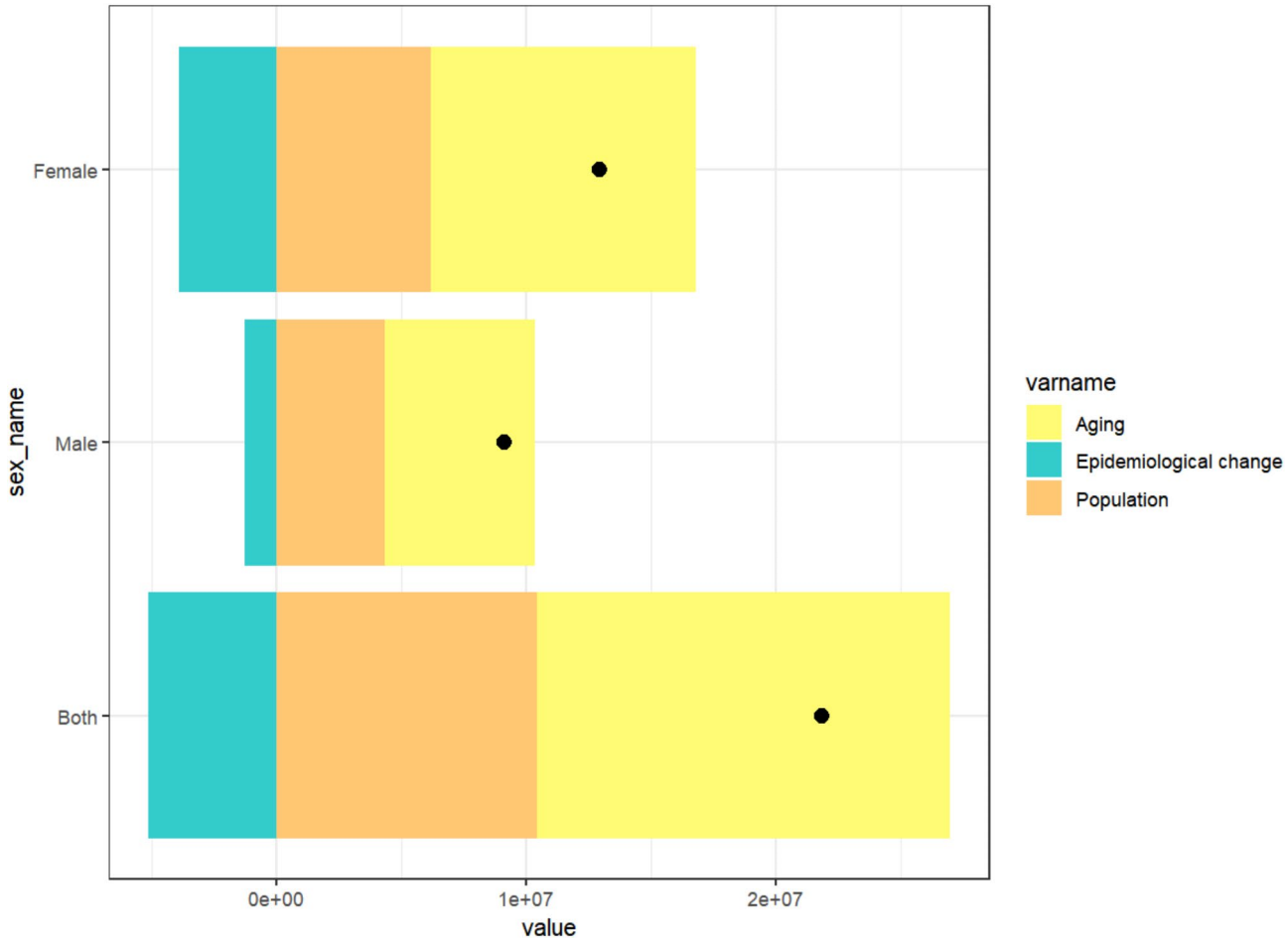

Fig. 3. Decomposition analysis: breaking down the factors affecting changes in the number of people with the disease into changes in the age structure of the population, population growth, and epidemiological trends.

2.328; 95% CI 1.711–3.168; $P<0.001$). Sarcopenia, as determined by the AWGS 2019 criteria, was significantly associated with an increased risk of osteoporosis (OR 1.478; 95% CI 1.286–1.697; $P<0.001$) and a higher risk of PHF (OR 1.485; 95% CI 1.105–1.997; $P<0.01$).

Similarly, as shown in Table 5, the associations between sarcopenia and PMOF, PHF, and osteoporosis in non-diabetic patients were examined using four distinct diagnostic criteria. The uncorrected logistic regression analysis provided the results. As determined by the IWGS criteria, Sarcopenia was associated with a significantly increased risk of osteoporosis (OR 2.210; 95% CI 1.743–2.801; $P<0.001$). Sarcopenia, as determined by the FNIH criteria, was significantly associated with an increased risk of osteoporosis (OR 1.937; 95% CI 1.530–2.451; $P<0.01$). As determined by the EWGSOP criteria, Sarcopenia was associated with a significantly higher risk of osteoporosis (OR 2.727; 95% CI2.117–3.513; $P<0.001$). Sarcopenia, as determined by the AWGS 2019 criteria, was associated with a significantly increased risk of osteoporosis (OR 2.321; 95% CI 1.834–2.937; $P<0.001$).

Correlation between sarcopenia adjudicated by four criteria and PMOF, PHF, and osteoporosis (corrected)

Table 6 further elaborates on the relationship between sarcopenia and PMOF, PHF, and osteoporosis in diabetic patients, assessed according to four diagnostic criteria. The corrected logistic regression analysis revealed significant findings. Patients with sarcopenia, as classified by the IWGS criteria, showed a significantly increased risk of developing osteoporosis (OR 1.486, 95% CI 1.304–1.694, $P<0.001$). Those assessed using the EWGSOP criteria also demonstrated a substantially increased risk of osteoporosis (OR 2.893, 95% CI 2.497–3.351, $P<0.001$), as well as higher risks for PMOF (OR 4.393, 95% CI 1.944–9.929, $P<0.001$) and PHF (OR 2.328, 95% CI 1.711–3.168, $P<0.001$). Patients evaluated using the AWGS 2019 criteria faced significantly increased risks for osteoporosis (OR 1.478, 95% CI 1.286–1.697, $P<0.001$) and PHF (OR 1.485, 95% CI 1.105–1.997, $P<0.01$). Reiterating these associations, Table 5 highlighted similar trends in non-diabetic patients, where sarcopenia, as determined by IWGS criteria, was linked to a significantly higher risk of developing osteoporosis (OR 2.210, 95% CI 1.743–2.801, $P<0.001$). Participants with sarcopenia, as classified by the FNIH criteria, exhibited a significantly increased risk of developing osteoporosis (OR 1.937, 95% CI 1.530–2.451, $P<0.01$). Participants diagnosed with sarcopenia according to the EWGSOP criteria exhibited a significantly increased risk of developing osteoporosis (OR 2.727, 95% CI 2.117–3.513, $P<0.001$). Participants classified using the AWGS 2019

Parameter	Total (8180 cases)	Diabetic patients (6035 cases)	Non-diabetic patients (2145 cases)	*P* value
Age (years)	63 (56, 70)	64 (58, 71)	59 (54, 65)	0.001
Male (cases, %)	4068 (49.7)	3040 (50.4)	1028 (47.9)	0.053
BMI (kg/m^2)	24.46 ± 3.43	24.57 ± 3.56	24.15 ± 3.03	0.001
Height (m)	1.60 (1.54, 1.66)	1.60 (1.54, 1.66)	1.61 (1.55, 1.67)	0.001
Weight (kg)	62.86 ± 10.64	62.86 ± 10.81	62.85 ± 10.15	0.984
SBP (mmHg)	132 (120, 145)	138 (130, 150)	119 (106, 120)	0.001
DBP (mmHg)	78 (70, 85)	80 (73, 87)	72 (66, 79)	0.001
Low-density lipoprotein cholesterol (mmol/L)	2.90 (2.32, 3.62)	2.80 (2.20, 3.54)	3.24 (2.60, 3.77)	0.01
High-density lipoprotein cholesterol (mmol/L)	1.27 (0.97, 1.55)	1.19 (0.91, 1.44)	1.48 (1.24, 1.80)	0.001
Total Cholesterol (mmol/L)	4.76 (3.99, 5.61)	4.57 (3.79, 5.44)	5.29 (4.58, 5.87)	0.02
Triglycerides (mmol/L)	1.41 (0.94, 2.10)	1.48 (0.97, 2.20)	1.30 (0.88, 1.79)	0.001
Aspartate aminotransferase (U/L)	21.00 (16.00, 28.00)	19.00 (15.00, 25.00)	26.00 (21.00, 36.00)	0.001
Creatinine (μmol/L)	56.00 (43.50, 71.00)	56.80 (44.60, 72.00)	54.80 (8.24, 67.95)	0.001
Neutrophil (×10^{12}/L)	3.64 (2.79, 4.80)	3.81 (2.92, 5.14)	3.23 (2.55, 4.12)	0.001
White blood cells (×10^{12}/L)	6.22 (5.10, 7.52)	6.40 (5.20, 7.75)	5.71 (4.77, 6.75)	0.001
Red blood cells (×10^{12}/L)	4.44 (4.13, 4.76)	4.37 (3.96, 4.69)	4.64 (4.38, 4.94)	0.001
Hemoglobin (g/L)	132.00 (118.00, 143.00)	128.00 (113.00, 139.00)	141.00 (131.00, 149.00)	0.001
Platelet (×1012/L)	214.00 (147.00, 261.00)	211.00 (142.00, 259.00)	223.00 (163.00, 264.00)	0.11
ALM	16.66 (14.27, 20.15)	16.8 (14.26, 20.12)	16.07 (14.19, 20.13)	0.688
ALM/Ht^2	6.62 (5.84, 7.48)	6.65 (5.96, 7.41)	6.34 (5.47, 7.71)	0.001
ALM/BMI	0.7 (0.59, 0.83)	0.70 (0.59, 0.83)	0.68 (0.58, 0.83)	0.163
PMOF	2.60 (1.80, 3.80)	2.60 (1.80, 3.90)	2.40 (1.90, 3.40)	0.001
PHF	0.60 (0.30, 1.20)	0.60 (0.30, 1.30)	0.50 (0.30, 1.00)	0.001
Osteoporosis (cases, %)	1465 (17.9)	1128 (18.7)	337 (15.1)	0.002

Table 3. Basic clinical characteristics of the study subjects [mean ± SD, n (%), M (P25, P75)].

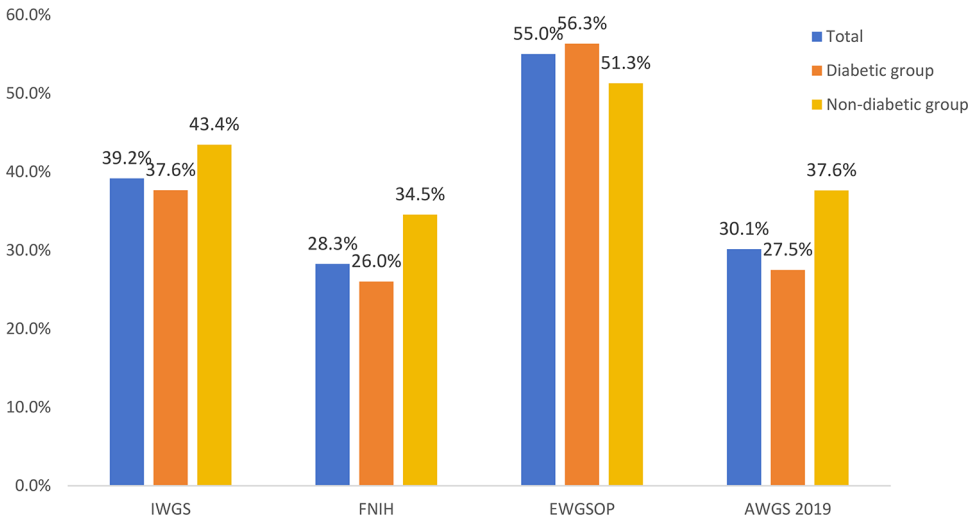

Fig. 4. Prevalence of sarcopenia as determined by the four criteria of IWGS, FNIH, EWGSOP, and AWGS 2019.

criteria also demonstrated a significantly higher risk of osteoporosis (OR 2.321, 95% CI 1.834–2.937, $P<0.001$). Similarly, participants assessed using the EWGSOP criteria demonstrated a markedly higher risk, with an OR of 2.727 and a 95% CI of 2.117–3.513 ($P<0.001$). Participants evaluated with the Asian Working Group on Sarcopenia (AWGS) 2019 criteria also faced a significantly increased risk of osteoporosis, with an OR of 2.321 and a 95% CI of 1.834–2.937 ($P<0.001$).

As illustrated in Table 6, the relationships between sarcopenia and PMOF, PHF, and osteoporosis were assessed in diabetic patients. These assessments were based on four distinct diagnostic criteria and adjusted for age, gender, and BMI. The corrected logistic regression analyses revealed that sarcopenia significantly increased the risk of developing osteoporosis and fractures. Specifically, using the IWGS criteria, subjects with sarcopenia

Diagnostic criteria	Osteoporosis	MHR-MOF	MHR-HF
IWGS	1.486 (1.304–1.694)***	1.564 (0.849–2.881)	1.280 (0.964–1.701)
FNIH	0.915 (0.788–1.063)	1.702 (0.907–3.194)	1.207 (0.889–1.639)
EWGSOP	2.893 (2.497–3.351)***	4.393 (1.944–9.929)***	2.328 (1.711–3.168)***
AWGS 2019	1.478 (1.286–1.697)***	1.343 (0.702–2.566)	1.485 (1.105–1.997)**

Table 4. Logistic regression analysis of the correlation between sarcopenia as determined by the four criteria IWGS, FNIH, EWGSOP, and AWGS 2019 and moderate to high risk of major osteoporotic fracture (MHR-MOF, PMOF > 10%) in the next 10 years, moderate to high risk of hip fracture (MHR-HF, PHF > 1%) in the next 10 years and osteoporosis in diabetic patients (uncorrected). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Diagnostic criteria	Osteoporosis	MHR-MOF	MHR-HF
IWGS	2.210 (1.743–2.801)***	1.397 (0.527–3.705)	3.963 (0.520–30.205)
FNIH	1.937 (1.530–2.451)***	0.752 (0.380–1.488)	1.876 (0.657–5.354)
EWGSOP	2.727 (2.117–3.513)***	/	/
AWGS 2019	2.321 (1.834–2.937)***	1.145 (0.537–2.442)	3.668 (0.832–16.172)

Table 5. Logistic regression analysis of the correlation between sarcopenia as determined by the four criteria IWGS, FNIH, EWGSOP, and AWGS 2019 and MHR-MOF, MHR-HF, and osteoporosis in non-diabetic patients (uncorrected). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Diagnostic criteria	Osteoporosis	MHR-MOF	MHR-HF
IWGS	1.233 (1.030–1.477)*	2.194 (0.995–4.840)	1.073 (0.733–1.570)
FNIH	1.696 (1.400–2.054)***	3.288 (1.557–6.945)**	1.655 (1.140–2.402)**
EWGSOP	1.587 (1.331–1.892)***	3.548 (1.426–8.826)**	1.554 (1.075–2.245)*
AWGS 2019	1.394 (1.149–1.691)**	1.833 (0.808–4.161)	1.429 (0.964–2.120)

Table 6. Logistic regression analysis of the correlation between sarcopenia as determined by the four criteria IWGS, FNIH, EWGSOP, and AWGS 2019 and MHR-MOF, MHR-HF, and osteoporosis in diabetic patients (corrected). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Diagnostic criteria	Osteoporosis	MHR-MOF	MHR-HF
IWGS	2.218 (1.030–1.477)***	2.471 (0.852–7.163)	3.574 (0.410–31.167)
FNIH	3.394 (2.407–4.786)***	1.324 (0.396–4.420)	3.529 (0.537–23.218)
EWGSOP	3.086 (2.359–4.037)***	/	/
AWGS 2019	3.539 (2.624–4.772)***	2.331 (0.942–5.770)	3.899 (0.714–21.300)

Table 7. Logistic regression analysis of the correlation between sarcopenia as determined by the four criteria IWGS, FNIH, EWGSOP, and AWGS 2019 and MHR-MOF, MHR-HF, and osteoporosis in non-diabetic patients (corrected). *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

demonstrated an increased likelihood of osteoporosis (OR 1.233, 95% CI 1.030–1.477, $P < 0.05$). The FNIH criteria indicated a more pronounced risk, with significant increases in osteoporosis (OR 1.696, 95% CI 1.400–2.054, $P < 0.001$), PMOF (OR 3.288, 95% CI 1.557–6.945, $P < 0.01$), and PHF (OR 1.655, 95% CI 1.140–2.402, $P < 0.01$). Furthermore, under the EWGSOP criteria, participants had a significantly increased risk of developing osteoporosis (OR 1.587, 95% CI 1.331–1.892, $P < 0.001$), a higher incidence of PMOF (OR 3.548, 95% CI 1.426–8.826, $P < 0.01$), and (OR 1.554, 95% CI 1.075–2.245, $P < 0.05$). Participants assessed with the AWGS 2019 criteria also showed a significantly increased risk of developing osteoporosis (OR 1.394, 95% CI 1.149–1.691, $P < 0.01$). As presented in Table 7, after adjustments for age, sex, and BMI, the relationships between sarcopenia and PMOF, PHF, and osteoporosis in non-diabetic participants were analyzed. Corrected logistic regression analysis indicated that participants with sarcopenia, as defined by the IWGS criteria, had a significantly higher risk of developing osteoporosis (OR 2.218, 95% CI 1.030–1.477, $P < 0.001$). Those defined by the FNIH criteria faced an even greater risk (OR 3.394, 95% CI 2.407–4.786, $P < 0.001$). Participants evaluated under EWGSOP criteria also demonstrated a significantly higher risk (OR 3.086, 95% CI 2.359–4.037, $P < 0.001$), as did those under the AWGS 2019 criteria (OR 3.539, 95% CI 2.624–4.772, $P < 0.001$).

Parameter	Sarcopenia (n = 4499)	Non-sarcopenia (n = 3681)	Z-value	*P* value	Spearman's correlation coefficient
Osteocalcin (ng/mL)	12.385 (8.170, 16.660)	12.505 (7.980, 17.200)	−0.574	0.566	−0.008
PINP (ng/mL)	32.690 (23.440, 45.250)	33.605 (22.465, 47.640)	−2.295	0.022	−0.034
β-CTX (ng/L)	330.00 (197.00, 510.00)	330.00 (210.00, 510.00)	−0.395	0.693	−0.006
ALM	14.620 (13.310, 17.640)	20.280 (16.43, 22.397)	−52.123	0.001	−0.308
ALM/Ht^2	6.018 (5.463, 6.646)	7.483 (6.750, 8.221)	−56.916	0.001	−0.261
ALM/BMI	0.640 (0.560, 0.760)	0.780 (0.650, 0.890)	−32.094	0.001	−0.252

Table 8. Comparison of bone metastasis markers between sarcopenia and non-sarcopenia groups.

Parameter	Wald	*P* value	OR (95% CI)
PINP	8.236	0.004	0.996 (0.993–0.999)
Osteocalcin	1.845	0.174	0.996 (0.989–1.002)
β-CTX	6.645	0.010	1.000 (0.999–1.000)
ALM	680.179	0.001	0.765 (0.749–0.780)
ALM/Ht2	474.405	0.001	0.535 (0.505–0.566)
ALM/BMI	441.417	0.001	0.010 (0.007–0.016)

Table 9. Logistic regression analysis of the correlation between bone metastasis markers and sarcopenia.

Differences in bone metastasis markers and body composition index between sarcopenia and non-sarcopenia groups under EWGSOP criteria

There was no significant difference in the concentrations of osteocalcin and β-C-terminal telopeptide of type I collagen (β-CTX) between the sarcopenia and non-sarcopenia groups ($P > 0.05$). However, the difference in the Procollagen Type 1 N-terminal Propeptide (PINP) levels was statistically significant, with a *P* value of 0.022 ($P < 0.05$), indicating higher levels in the sarcopenia group (mean PINP 32.690, range 23.440–45.250) compared to the non-sarcopenia group (mean PINP 33.605, range 22.465–47.640). Regarding Spearman's correlation coefficients, values were notably negative, with −0.034 overall. Specifically, for ALM, it was −0.308 to 0.261 for ALM/Ht^2 and −0.252 for ALM/BMI. These results indicate a negative correlation between these variables and the occurrence of sarcopenia, as detailed in Table 8.

Correlation between PINP, ALM, ALM/Ht^2, and ALM/BMI and osteoporosis

In earlier analyses, a negative and statistically significant correlation was observed between PINP, ALM, ALM/Ht^2, and ALM/BMI and the occurrence of sarcopenia. Subsequent analyses extended these findings to osteoporosis, with *P* values of 0.004, 0.001, 0.001, and 0.001, respectively, confirming statistical significance (*P* value < 0.05). According to the results of this study, PINP, ALM, ALM/Ht^2, and ALM/BMI were found to have significant effects on osteoporosis. Specifically, the OR for PINP was 0.996 (95% CI 0.993–0.999), indicating that PINP is a protective factor against osteoporosis. The OR for ALM was 0.765 (95% CI 0.749–0.780), the OR for ALM/Ht^2 was 0.535 (95% CI 0.505–0.566), and the OR for ALM/BMI was 0.010 (95% CI 0.007–0.016). All of these variables demonstrated protective effects against osteoporosis (Table 9).

Discussion

The global burden of disease study has documented a steady increase in the prevalence of MSDs in both China and across the globe. This rise is primarily attributed to population aging, with China bearing the world's largest aging population. Consequently, the early identification and prevention of MSDs have become critical, underscoring the clinical significance of the present study. In this study, we identified a strong association between sarcopenia and osteoporosis, as well as with the MHR-MOF and MHR-HF in the cohort from the First Affiliated Hospital of Fujian Medical University. The correlation between sarcopenia and osteoporosis has gained increasing attention in recent years. As early as 2009, Binkley et al. introduced the concept of osteo-sarcopenia, emphasizing that fractures in older adults are not solely attributable to osteoporosis but are also closely linked to sarcopenia[10]. Osteoporosis and sarcopenia often coexist, a relationship that is further corroborated by the findings of this study.

Currently, the primary focus of fracture prevention and treatment in the elderly population remains centered on improving bone health, often through interventions to increase bone mass. However, the complex interplay between bone and muscle, which share common regulatory pathways, is frequently neglected[7,10,23–25]. By addressing osteoporosis and sarcopenia as interconnected conditions, we can effectively reduce fall and fracture incidence, improve patients' quality of life, and optimize long-term prognostic outcomes.

Although the diagnostic criteria for sarcopenia share many similarities, subtle differences in their definitions can lead to variability in diagnosis. Each diagnostic framework incorporates three core components: gait speed, muscle mass, and muscle strength. This study also assessed the prevalence of sarcopenia using different diagnostic criteria, finding variations across the IWGS, FNIH, EWGSOP, and AWGS 2019 criteria, with prevalences of 39.2%, 28.3%, 55.0%, and 30.1%, respectively. This variability highlights the impact of diagnostic

criteria selection on sarcopenia prevalence estimates. We further analyzed the relationship between sarcopenia and osteoporosis, PMOF, and PHF across the four diagnostic criteria. Further analyses corrected for age, BMI, and gender indicated that sarcopenia was significantly correlated with osteoporosis under all four diagnostic criteria, regardless of diabetes status. Notably, in the diabetic population, sarcopenia, as defined by FNIH and EWGSOP criteria, also showed significant correlations with MHR-MOF and MHR-HF. In addition, in the diabetic population, sarcopenia diagnosed using the FNIH and EWGSOP criteria demonstrated the ability to identify individuals at high-risk PMOF and PHF. This predictive capability is of substantial clinical value for the early detection and prevention of osteoporosis and fracture in patients with diabetic sarcopenia.

Among the evaluated bone metabolic markers and body composition indices, PINP, ALM, ALM/Ht^2, and ALM/BMI exhibited significant differences between the sarcopenia and non-sarcopenia groups. All four parameters were negatively correlated with sarcopenia and osteoporosis, suggesting their potential role as protective factors. PINP, a metabolic marker of bone formation, is recognized as a specific biochemical indicator of bone formation. Elevated PINP levels indicate high bone turnover, while reduced PINP levels may reflect impaired bone formation. PINP is commonly used in clinical practice to monitor bone growth and skeletal development. In this study, PINP was negatively associated with sarcopenia and served as a protective factor against osteoporosis. The data suggest that reduced PINP levels in sarcopenic patients might lead to osteoporosis, proposing that diminished PINP could be a pathway through which sarcopenia influences osteoporosis. Additionally, higher muscle strength enhances mechanical loading on bone tissue, thereby adaptively increasing PINP levels and promoting bone formation to counteract osteoporosis progression. This finding aligns with prior research[26]. In addition, ALM exhibited a significant negative correlation with sarcopenia and was identified as a protective factor against osteoporosis. The association persisted after corrections for Ht^2 and BMI, emphasizing that ALM is crucial in the pathway from sarcopenia to osteoporosis, supporting earlier findings[26]. Given the limitations of this study, there is a compelling need for prospective studies with larger sample sizes. Such research would further delineate the role of sarcopenia in the development of bone damage and aid in the development of diagnostic criteria capable of simultaneously diagnosing sarcopenia and predicting the onset of osteoporosis, the risk of major site fractures, and hip fractures over the next decade.

Conclusion

This investigation highlights the increasing prevalence of MSDs both globally and in China, primarily driven by an aging population. It was demonstrated that sarcopenia is significantly associated with osteoporosis across all examined diagnostic criteria and predicts MHR-MOF and MHR-HF in diabetic individuals, particularly when using FNIH and EWGSOP criteria. Additionally, PINP was found to be inversely related to sarcopenia and served as a protective factor against osteoporosis. Due to the limitations of this study, further multi-center prospective studies with larger sample sizes are necessary to enhance the generalizability of these findings, clarify the role of sarcopenia in bone damage, and develop diagnostic criteria that can simultaneously diagnose sarcopenia and forecast the risk of osteoporosis and fractures over the next decade.

Data availability

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

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Zhenrun Zhan: Formal analysis, writing. Yongze Zhang: Formal analysis, methodology. Jiayong Wu: Data curation. Jiebin Lin: Project administration. Sunjie Yan: review and editing.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics statement
This study was approved by the ethics committee of the First Affiliated Hospital of Fujian Medical University, and written informed consent was obtained from the patients: MRCTA, ECFAH of FMU (2017)131. The authors confirm that all experiments were performed following relevant guidelines and regulations.

Additional information
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