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A comparative analysis of sarcopenia screening methods in Thai people with type 2 diabetes mellitus in an outpatient setting

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Abstract

Background Type 2 Diabetes Mellitus (T2DM) is closely linked with sarcopenia. The lack of validated, easy, and effective sarcopenia screening tools for people with T2DM may result in underdiagnosis, delayed interventions, and worsening outcomes. This study evaluated and compared the diagnostic accuracy of various sarcopenia screening tools in T2DM outpatients.

Methodology A cross-sectional study was conducted on 329 people with T2DM at Phramongkutklao Hospital, Thailand, between December 2023 and November 2024. This study compared eight sarcopenia screening tools. The Asian Working Group for Sarcopenia 2019 (AWGS 2019) criteria served as the reference standard. Sensitivity, Specificity, and diagnostic accuracy were evaluated using receiver operating characteristic (ROC) curve analysis. The optimal cutoffs were identified with the Youden index.

Results The prevalence of sarcopenia was 23.7%. Calf circumference showed the highest diagnostic accuracy at standard cutoff (AUC: 0.892), with optimised cutoff points of < 37.0 cm for males and < 36.0 cm for females, and achieved high sensitivity (90.1% for males, 91.1% for females) with acceptable specificity (77.2% for males, 67.8% for females). Neck circumference demonstrated diagnostic utility (AUC: 0.741) with proposed thresholds of < 39.5 cm (males) and < 36.5 cm (females), yielding moderate sensitivity (69.7% for males, 82.2% for females) and acceptable specificity (78.9% for males, 62.6% for females). Questionnaire-based tools showed limited diagnostic accuracy with SARC-CalF performing the best (AUC: 0.789, sensitivity: 48.7%, specificity: 93.2%). Among physical performance tests, handgrip strength was the most accurate (AUC: 0.716), although these tests generally exhibited high sensitivity, but lower specificity.

Conclusion Calf circumference was the most effective screening tool for sarcopenia in people with T2DM. Neck circumference emerged as a promising alternative at optimal cutoff values, offering a simple, novel and practice screening tool option. These findings support the implementation of anthropometric measures for sarcopenia screening in clinical settings, particularly in outpatient care.

Keywords Sarcopenia, Type 2 Diabetes Mellitus, Screening Tools, Sensitivity, Specificity

Introduction

Diabetes mellitus is a metabolic disease caused by deficiencies in insulin secretion and/or insulin resistance [1, 2]. Insulin resistance has been closely associated with increased muscle protein degradation [3, 4].

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Accumulation of Advanced Glycation End Products (AGEs) induces skeletal muscle atrophy and dysfunction, while oxidative stress and mitochondrial dysfunction caused by Type 2 Diabetes Mellitus (T2DM) can lead to myocyte apoptosis. As such, people with T2DM have a higher risk of developing sarcopenia, a progressive and generalised skeletal muscle disease linked to a higher risk of negative consequences such as falls, fractures, physical disability, and mortality [5].

Beyond sarcopenia, T2DM is also associated with frailty [6, 7], a condition similarly characterised by chronic inflammation [8], and closely interrelated with sarcopenia through common pathophysiological mechanisms [9]. Moreover, inflammatory cytokines also prompt anabolic hormones to be downregulated and increase muscle catabolism, resulting in further muscle loss [10]. Given this complex interplay, early detection of sarcopenia in T2DM outpatients is crucial to prevent functional decline and improve outcomes.

Currently, various tools, such as dual-energy X-ray absorptiometry (DXA) [11] and bioelectrical impedance analysis (BIA) [12], which has demonstrated good agreement with DXA in measuring body composition [13], have been utilised to diagnose sarcopenia by measuring muscle mass. However, these methods following the AWGS2019 standards [14] require specialised equipment and are not always feasible in routine outpatient care.

Sarcopenia screening has been widely studied in community settings and hospitalised patients, but less so in outpatients with T2DM. Community-based screening often relies on simple, non-invasive tools [15], whereas hospital-based studies involve more comprehensive assessments with varied ways of muscle mass measurement [16, 17]. Outpatients, particularly those with T2DM, represent an intermediate group — they are at high risk of sarcopenia, yet may not receive systematic screening in routine clinical visits.

Identifying the most suitable non-invasive and easy-to-use screening tool for clinical settings remains a challenge, particularly for adults with T2DM, where limited studies have assessed the performance of these tools, hindering intervention implementation. Previously, a study examined the performance of SARC-CalF and SARC-F, showing their effectiveness [18]. Nevertheless, the examination was based on hospitalised patients who were compared using only two screening tools, not fully reflecting people with T2DM in outpatients who differ in disease severity, functional status, and access to care.

This cross-sectional study was performed on outpatients to address this gap by evaluating the performance of multiple sarcopenia screening tools. By identifying the most suitable tool for clinical use, this study sought to enhance early detection, enabling timely interventions such as resistance training and nutritional optimisation, which are known to improve muscle function and metabolic health [19, 20].

Methodology

Between December 2023 and November 2024, a cross-sectional study involving 329 people with T2DM was conducted at Phramongkutklao Hospital in Bangkok, Thailand. The study's inclusion criteria required people with T2DM who were at least 60 years old and willing to participate. The exclusion criteria included having active cancer, experiencing weakness or limited mobility due to neurological impairments, having other uncontrolled underlying conditions, an inability to undergo a physical test, and taking medications that affect muscle mass, such as steroids. The study received approval from the Royal Thai Army Institutional Board Review under the reference R080h/66, and written informed consent was obtained from all participants before their participation.

The sample size was determined based on a study by Anand Shahi et al., which investigated the prevalence of sarcopenic in patients with type 2 diabetes. The study reported a prevalence of sarcopenic of 18.8%. The following parameters were used for calculation: significance level (α) at 0.05 (corresponding to a 95% confidence level), prevalence (P) at 18.8% (0.188) and margin of error (D) at 5.0%. As a result, the required sample size was calculated to be 235 samples. To account for potential incomplete data, an additional 20% was added, resulting in a final minimum required sample size of 294 samples.

Screening tools for sarcopenia

This study aimed to investigate the following screening tools for sarcopenia shown in Fig. 1 in people with T2DM.

1. Calf circumference (CC) measures the maximal circumference in a seated position with feet on the floor and the non-dominant leg at 90° with a measuring tape. Men with a maximum CC of < 34 cm and women with a maximum CC of < 33 cm are considered to have low CC [14].
2. Neck circumference (NC) measures the circumference of the middle of the neck with a measuring tape. A measurement of < 32.8 cm for females and < 38.0 cm for males is considered positive sarcopenia screening [21].
3. The SARC-F consists of five screening questions that examine five domains: strength, walking assistance, rising from a chair, climbing stairs, and falls. Each question is answered with a score ranging from 0 to 2, resulting in a total score of 0 to 10. A score greater

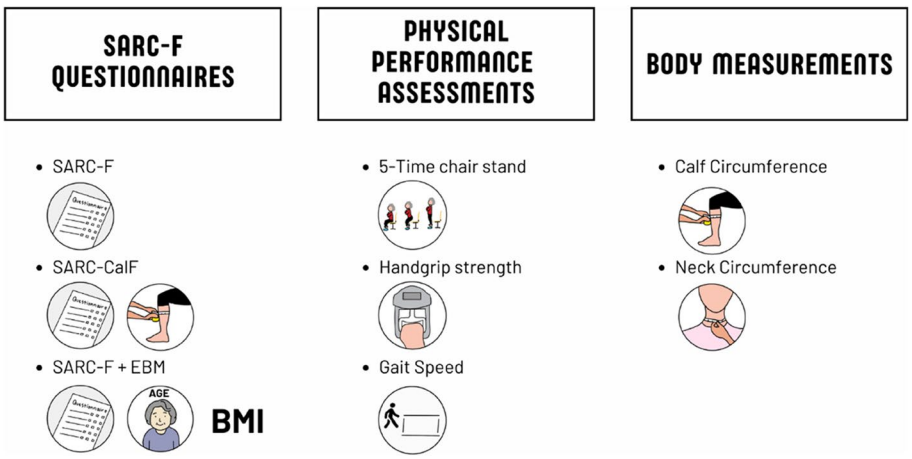

Fig. 1 Infographic representation of screening tools for sarcopenia in this study

than or equal to 4 is considered positive sarcopenia screening [22].

4. SARC-CalF consists of the five-question SARC-F questionnaire and an additional CC measurement. Men with a maximum CC of < 34 cm and women with a maximum CC of < 33 cm are assigned another 10 points. The total scores range from 0 to 20. A score greater than or equal to 11 is considered positive sarcopenia screening [23].
5. SARC + EBM consists of the SARC-F questionnaire with the same five questions and incorporates scores based on age and Body Mass Index (BMI) assessments. People under 75 are assigned a zero score, while those over 75 are assigned a 10 score. For BMI, people with a BMI > 21 kg/m^2 were assigned a zero score, and those with a BMI ≤ 21 kg/m^2 received a 10 score. The SARC-F + EBM score ranges from 0 to 30. A score greater than or equal to 12 is considered positive sarcopenia screening [24].
6. The chair stand time records the time in seconds needed to complete five repetitions of standing up and sitting in a chair. A completion time equal to or greater than 12 s is considered the cutoff for low physical performance [14].
7. A digital hand dynamometer assessed handgrip strength. Initially, participants used their dominant hand while seated, maintaining a 90-degree elbow flexion, and performed three grip tests. The best performance from these tests was recorded in kilograms. Low handgrip muscle strength categorisation by the AWGS 2019 guidelines stands at < 28.0 kg for men and < 18.0 kg for women [14].
8. The gait speed test measures the time required for participants to walk 6 m at a standard pace. Two trials were conducted, and the resulting average was calculated in metres per second. A gait speed of less than 1.0 m per second in the 6-m walk is considered the cutoff for low physical performance [14].

Definition of sarcopenia

The AWGS 2019 algorithm for sarcopenia was used to diagnose sarcopenia. The handgrip strength test and 5-times chair stand test assessed muscle strength and physical performance. Appendicular skeletal muscle mass (ASM) was measured by DXA and BIA. The lean mass, ASM, was divided by height squared (kg/m^2) to determine the skeletal muscle mass index (SMI). Individuals were categorised as having low muscle mass when their SMI fell below 7.0 kg/m^2 for men and 5.7 kg/m^2 for women as per the AWGS 2019 criteria for diagnosing sarcopenia measured by BIA (Inbody 970) used in this study [14]. Sarcopenia is described as low ASM, and either lowered muscle strength which is measured by hand grip strength, or decreased physical performance which is evaluated by chair stand time and gait speed tests.

Statistical analysis

Continuous variables with a normal distribution were expressed as mean and standard deviation (SD), while non-normally distributed quantitative variables were summarised as median and interquartile range (IQR). Sensitivity, specificity, positive likelihood ratio (+ LR), negative likelihood ratio (− LR), positive predictive value (PPV), and negative predictive value (NPV) were calculated using the AWGS 2019 criteria as the reference standard for diagnosing sarcopenia. The diagnostic performances for calf circumference, neck circumference, SARC-F, SARC-CalF, SARC-F + EBM, handgrip strength,

chair stand time, and gait speed were assessed through receiver operating characteristic (ROC) curve analysis with the area under the curve (AUC). The Youden index (Sensitivity + Specificity − 1) was applied to identify optimal ROC cutoff points. Statistical analyses involved using the Chi-square test for categorical variables, while continuous variables were analysed with either the independent t-test or the Mann–Whitney U test. Differences in sensitivity and specificity among the screening tools were evaluated using the Marascuillo procedure, and the area under the curve was compared using the DeLong method. Analyses were performed with STATA software (StataCorp. 2023. *Stata Statistical Software:* Release 18. College Station, TX: StataCorp LLC), using two-sided statistical tests, with significance set at a p-value below 0.05.

Results

This study examined 329 individuals with T2DM. 169 (51.4%) of the study population. The mean age (SD) and disease duration (IQR) of the population were 69.7 (7.4) and 10 [5, 20], respectively. According to the AWGS 2019 criteria, 78 people were diagnosed with sarcopenia, resulting in the prevalence of 23.7% (Fig. 2). As shown in Table 1, individuals with sarcopenia were significantly older (73.9 ± 8.2 vs. 68.3 ± 6.6 years, $P < 0.001$) and had lower BMI ($P < 0.05$). The majority of those with sarcopenia, 52.6%, had a BMI of 18.5–22.9, whereas 68.9% of people without sarcopenia had a BMI ≥ 25.0. Education is also a factor affecting the manifestation of sarcopenia. Lower education levels were associated with higher sarcopenia prevalence, with 32.1% of sarcopenic individuals having only primary or no education, compared to 20% in the non-sarcopenic group. Additionally, frailty phenotype was more common in the sarcopenic group (30.8% vs. 11.2%). Neither diabetic nephropathy nor duration of T2DM significantly affected the diagnosis of sarcopenia, with a mean of 10 years for both groups. Table 2 summarises the factors associated with sarcopenia prevalence in people with T2DM.

Performance of screening tools at standard cut-off values

From Tables 3 and 4, people with T2DM with sarcopenia had significantly lower mean body measurements ($P < 0.001$), including calf circumference (33.0 ± 2.4 cm), waist circumference (84.9 ± 11.0 cm), and neck circumference (36.3 ± 5.2 cm). CC was the most accurate, with an AUC of 0.892, the highest PPV of 70.8%, and a positive likelihood ratio of 7.79, despite lower sensitivity of 59.0%. NC had a low sensitivity of 33.3%, but higher specificity of 94.8%. Figure 3 presents the ROC curve analysis of sarcopenia screening tools.

Individuals with sarcopenia exhibited notably higher scores in SARC-CalF and SARC-F + EBM, along with a slightly higher score in SARC-F (median 10 vs. 1, $p < 0.001$; 11 vs. 2, $p < 0.001$; 2 vs 1, $p < 0.006$, respectively). Among SARC assessments, SARC-CalF was the most sensitive (48.7%) and had the highest specificity (93.2%), PPV (69.1%), NPV (85.4%), and positive likelihood ratio (7.19). SARC-F + EBM had higher sensitivity (35.9%) than SARC-F (25.7%), while both had similar specificity

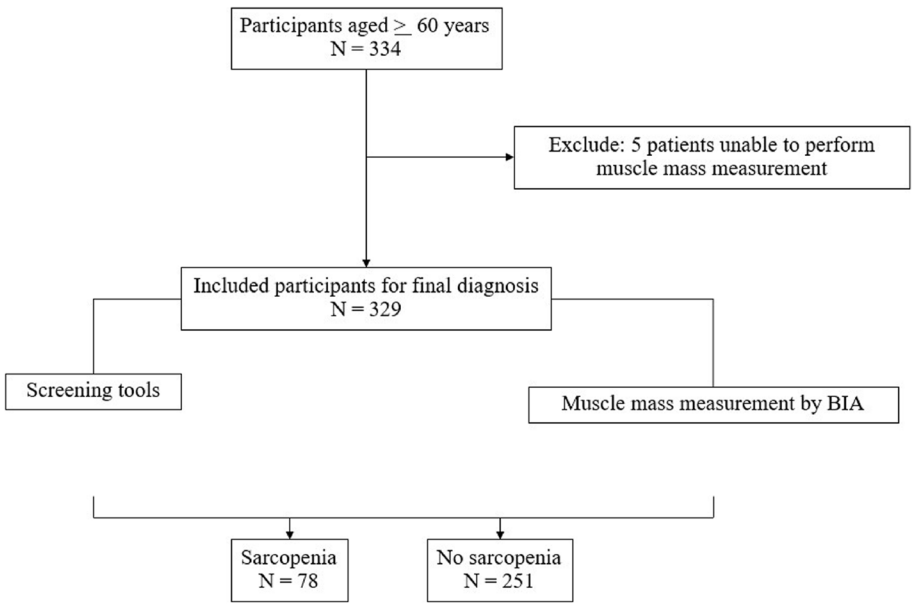

Fig. 2 Flowchart of sarcopenia screening tools and diagnosis based on AWGS 2019 criteria

Table 1 Baseline characteristics of T2DM patient

Variables	Total (*n* = 329)	Sarcopenia (*n* = 78)	Non- Sarcopenia (*n* = 251)	*P*-value
Age (years), mean ± SD	69.7 ± 7.4	73.9 ± 8.2	68.3 ± 6.6	< 0.001*
Sex, n (%)				
Male	169 (51.4)	33 (42.3)	136 (54.2)	0.067
Female	160 (48.6)	45 (57.7)	115 (45.8)	
Education, n (%)				
Primary school or less	75 (22.9)	25 (32.1)	50 (20.0)	0.007*
Secondary school/diploma	102 (31.1)	14 (18.9)	88 (35.2)	
Bachelor's degree or higher	151 (46.0)	39 (50.0)	112 (44.8)	
Weight (kg), mean ± SD	68.1 ± 14.5	54.1 ± 8.2	72.4 ± 13.2	< 0.001*
Height (cm), mean ± SD	161.2 ± 8.9	156.7 ± 8.3	162.6 ± 8.7	< 0.001*
Body mass index (kg/m^2), mean ± SD	26.1 ± 4.6	22.0 ± 2.9	27.4 ± 4.3	< 0.001*
BMI classification, n (%)				
< 18.5	9 (2.7)	7 (8.9)	2 (0.8)	< 0.001*
18.5–22.9	70 (21.3)	41 (52.6)	29 (11.6)	
23.0–24.9	69 (21.0)	22 (28.2)	47 (18.7)	
≥ 25.0	181 (55.0)	8 (10.3)	173 (68.9)	
Underlying disease, n (%)				
Hypertension	260 (79.0)	58 (74.4)	202 (80.5)	0.246
Dyslipidemia	288 (87.5)	69 (88.5)	219 (87.3)	0.777
Myocardial infarction/coronary artery disease	32 (10.3)	11 (14.7)	21 (8.9)	0.149
Cancer	18 (5.5)	6 (7.7)	12 (4.8)	0.323
Stroke	21 (6.4)	7 (8.9)	14 (5.6)	0.284
Diabetic nephropathy, n (%)	171 (51.9)	45 (57.7)	126 (50.2)	0.247
Duration of DM (years), median (IQR)	10 (5, 20)	10 (6, 20)	10 (5, 20)	0.220
Family history of DM, n (%)	225 (68.4)	51 (65.4)	174 (69.3)	0.514
Smoking, n (%)	16 (4.9)	2 (2.6)	14 (5.6)	0.280
Frailty phenotype, n (%)				
Non-frail	64 (19.5)	6 (7.7)	58 (23.1)	
Pre-frailty	213 (64.7)	48 (61.5)	165 (65.7)	< 0.001*
Frailty	52 (15.8)	24 (30.8)	28 (11.2)	
HbA1 C (%), median (IQR)	6.9 (6.3, 7.7)	7 (6.3, 7.7)	6.9 (6.3, 7.7)	0.698
UACR (mg/g), median (IQR)	16.7 (6.6, 58.5)	17.9 (7.5, 72.5)	16. 3 (6.0, 49.9)	0.424
GFR (mL/min/1.73 m^2), median (IQR)	68.7 (55.5, 85.3)	62.4 (50.3, 79.7)	70.7 (56.7, 86.0)	0.028*

Data were analysed with Chi-square test, independent t-test, and Mann–Whitney U test

* Statistically significant at the 0.05 level (α = 0.05)

of 87.7% and 86.1%. Overall, SARC-CalF exhibited the best performance, with an AUC of 0.789.

For physical fitness measurements, sarcopenic individuals exhibited lower hand grip strength (17.9 ± 7.0 kg) and gait speed (0.77 ± 0.25 m/s), but a significantly higher 5-times chair stand test (18.14 ± 5.80 s, $P < 0.001$). Although the 5-times chair stand test had the highest sensitivity of 90.5%, the specificity was compromised at 28.3%. Both handgrip strength and gait speed tests demonstrated a high sensitivity of 80.8% and 84.2%, but handgrip strength had a higher specificity of 55.8%, and was the most accurate at AUC of 0.716.

Comparison of cut-off values for arthrometric measurements

The performance of CC and NC was evaluated using the maximum Youden index in Table 5 to determine the best cutoff values. For CC, the optimal cutoff point was < 37.0 cm in males (sensitivity 90.9%, specificity 77.2%), and < 36.0 cm in females (sensitivity 91.1%, specificity 67.8%), with a high AUC of 0.820. Regarding NC, the best cutoffs were < 39.5 cm in males (sensitivity 69.7%, specificity 78.9%), and < 36.5 cm in females (sensitivity 82.2%, specificity 62.6%), with an AUC of 0.741. Combining CC and NC, yielded a sensitivity of 73.1%, and

Table 2 Factors Associated with Sarcopenia Prevalence

Variables	Total (*n* = 329)	Sarcopenia (*n* = 78)	Non- Sarcopenia (*n* = 251)	*P*-value
Age (years), mean ± SD	69.7 ± 7.4	73.9 ± 8.2	68.3 ± 6.6	< 0.001*
Education, n (%)				
Primary school or less	75 (22.9)	25 (32.1)	50 (20.0)	0.007*
Secondary school/diploma	102 (31.1)	14 (18.9)	88 (35.2)	
Bachelor's degree or higher	151 (46.0)	39 (50.0)	112 (44.8)	
Weight (kg), mean ± SD	68.1 ± 14.5	54.1 ± 8.2	72.4 ± 13.2	< 0.001*
Height (cm), mean ± SD	161.2 ± 8.9	156.7 ± 8.3	162.6 ± 8.7	< 0.001*
Body mass index (kg/m^2), mean ± SD	26.1 ± 4.6	22.0 ± 2.9	27.4 ± 4.3	< 0.001*
BMI classification, n (%)				
< 18.5	9 (2.7)	7 (8.9)	2 (0.8)	< 0.001*
18.5–22.9	70 (21.3)	41 (52.6)	29 (11.6)	
23.0–24.9	69 (21.0)	22 (28.2)	47 (18.7)	
≥ 25.0	181 (55.0)	8 (10.3)	173 (68.9)	
Frailty phenotype, n (%)				
Non-frail	64 (19.5)	6 (7.7)	58 (23.1)	
Pre-frailty	213 (64.7)	48 (61.5)	165 (65.7)	< 0.001*
Frailty	52 (15.8)	24 (30.8)	28 (11.2)	
GFR (mL/min/1.73 m^2), median (IQR)	68.7 (55.5, 85.3)	62.4 (50.3, 79.7)	70.7 (56.7, 86.0)	0.028*

Data were analysed with Chi-square test, independent t-test, and Mann–Whitney U test

* Statistically significant at the 0.05 level (α = 0.05)

Table 3 Comparison of sarcopenia assessments between T2DM patients with and without sarcopenia

Variables	Total (*n* = 329)	Sarcopenia (*n* = 78)	Non- Sarcopenia (*n* = 251)	*P*-value
Calf circumference (cm), mean ± SD	37.0 ± 4.0	33.0 ± 2.4	38.2 ± 3.6	< 0.001*
Waist circumference (cm), mean ± SD	94.5 ± 12.8	84.9 ± 11.0	97.5 ± 11.9	< 0.001*
Neck circumference (cm), mean ± SD	38.9 ± 4.2	36.3 ± 5.2	39.7 ± 3.5	< 0.001*
SARC-F, median (IQR)	1 (0, 3)	2 (1, 4)	1 (0, 2)	0.006*
SARC-F ≥ 4, n (%)	55 (16.7)	20 (25.6)	35 (13.9)	0.016*
SARC-CalF, median (IQR)	2 (1, 5)	10 (2, 13)	1 (0, 3)	< 0.001*
SARC-CalF ≥ 11, n (%)	55 (16.7)	38 (48.7)	17 (6.8)	< 0.001*
SARCF + EBM	2 (1, 10)	11 (3, 13)	2 (0, 4)	< 0.001*
SARCF + EBM ≥ 12, n (%)	59 (17.9)	28 (35.9)	31 (12.4)	< 0.001*
Hand grip strength (kg), mean ± SD	22.5 ± 7.9	17.9 ± 7.0	24.0 ± 7.6	< 0.001*
M < 28 kg; F < 18 kg, n (%)	174 (52.9)	63 (80.8)	111 (44.2)	< 0.001*
5-times chair stand (sec), mean ± SD	15.9 ± 5.5	18.1 ± 5.8	15.2 ± 5.3	< 0.001*
5-times chair stand ≥ 12 s, n (%)	242 (76.1)	67 (90.5)	175 (71.7)	0.001*
Gait speed (m/s), mean ± SD	0.85 ± 0.24	0.77 ± 0.25	0.87 ± 0.24	0.001*
Gait speed < 1 m/s, n (%)	245 (75.2)	64 (84.2)	181 (72.4)	0.037*
Skeleton muscle mass index (kg/m^2), mean ± SD	6.9 ± 1.2	5.6 ± 0.7	7.3 ± 1.0	< 0.001*
M < 7.0 kg/m^2; F < 5.7 kg/m^2, n (%)	89 (27.1)	78 (100.0)	11 (4.4)	< 0.001*

Data were analysed with an independent t-test and Mann–Whitney U test

* Statistically significant at the 0.05 level (α = 0.05)

Table 4 Diagnostic test evaluation of sarcopenia screening tools

Parameters	Sensitivity (95%CI)	Specificity (95%CI)	PPV (95%CI)	NPV (95%CI)	LR + (95%CI)	LR- (95%CI)	Accuracy (95%CI)	AUC (95%CI)
Calf circumference (M < 34 cm; F < 33 cm)	59.0[a,b] (47.3, 70.0)	92.4[a,b,c] (88.4, 95.4)	70.8 (58.2, 81.4)	87.9 (83.3, 91.6)	7.79 (4.87, 12.47)	0.44 (0.34, 0.58)	84.5 (80.1, 88.2)	0.892[1,2,3,4,5,6,7] (0.857, 0.927)
Neck circumference (M < 38 cm; F < 32.8 cm)	33.3[c,d,e] (23.1, 44.9)	94.8[d,e,f] (91.3, 97.2)	66.7 (51.9, 78.7)	82.1 (79.6, 84.3)	6.44 (3.48, 11.91)	0.70 (0.60, 0.82)	80.2 (75.5, 84.4)	0.785[1,8,9,10,11] (0.728, 0.841)
SARC-F (≥ 4)	25.6[a,f,g,h] (16.4, 36.8)	86.1 [h,i,j] (81.1, 90.1)	36.4 (26.0, 48.2)	78.8 (76.4, 81.1)	1.84 (1.13, 2.99)	0.86 (0.75, 0.99)	71.7 (66.5, 76.5)	0.602[2,8,12,13,14] (0.529, 0.674)
SARC-CalF (≥ 11)	48.7[i,j,k] (37.2, 60.3)	93.2 [k,l,m] (89.4, 96.0)	69.1 (57.3, 78.9)	85.4 (82.5, 87.9)	7.19 (4.31, 12.0)	0.55 (0.44, 0.68)	82.7 (78.1, 86.6)	0.789[3,12,15,16] (0.727, 0.852)
SARCF + EBM (≥ 12)	35.9 [l,m,n] (25.3, 47.6)	87.7[n,q,o] (82.9, 91.5)	47.5 (36.7, 58.5)	81.5 (78.7, 83.9)	2.91 (1.87, 4.53)	0.73 (0.62, 0.87)	75.4 (70.4, 79.9)	0.774[4,13,17,18] (0.715, 0.834)
Hand grip strength (M < 28 kg; F < 18 kg)	80.8[c,f,l,l] (70.3, 88.8)	55.8[a,d,h,k,n,p,r] (49.4, 62.0)	36.2 (32.2, 40.4)	90.3 (85.4, 93.7)	1.83 (1.53, 2.18)	0.34 (0.22, 0.55)	61.7 (56.2, 66.9)	0.716[5,9,14,19] (0.652, 0.781)
5-times chair stand (≥ 12 s)	90.5[b,d,g,j,m] (81.5, 96.1)	28.3[b,e,i,l,q,p] (22.7, 34.4)	27.7 (25.6, 29.9)	90.8 (82.6, 95.4)	1.26 (1.13, 1.41)	0.33 (0.16, 0.70)	42.8 (37.3, 48.4)	0.657[6,10,15,17] (0.588, 0.725)
Gait speed (< 1 m/s)	84.2[e,h,k,n] (74.0, 91.6)	27.6[c,f,j,m,o,r] (22.2, 33.6)	26.1 (23.8, 28.6)	85.2 (76.7, 90.9)	1.16 (1.03, 1.32)	0.57 (0.33, 1.00)	40.8 (35.4, 46.4)	0.623[7,11,16,18,19] (0.548, 0.697)

Identical letters indicate statistically significant differences at the 0.05 level between sensitivity and specificity by the Marascuillo procedure

Identical numbers indicate statistically significant differences at the 0.05 level between the AUC curves by the DeLong test

PPV Positive Predictive Value, *NPV* Negative Predictive Value, *LR* + Positive Likelihood Ratio, *LR*- Negative Likelihood Ratio, *AUC* Area under the curve

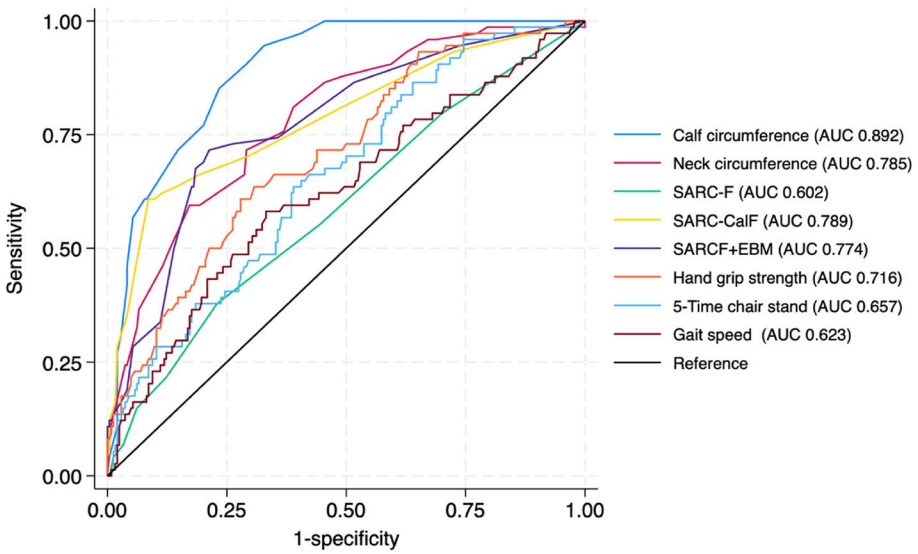

Fig. 3 ROC curve analysis of sarcopenia screening tools for discriminate sarcopenia in T2DM

specificity of 86.9%, with an AUC of 0.800, as shown in Fig. 4.

For optimal CC cutoff, the likelihood ratios (LR +) were 3.99 and 2.83, respectively, indicating that males and females with sarcopenia were 3.99 and 2.83 times more likely to test positive than those without sarcopenia. The positive post-test probabilities were 55.0% for males and 47.0% for females. For the best NC, the LR + was 3.27 for males and 2.20 for females, with corresponding post-test probabilities of 50.0% and 41.0%. Combining both CC and NC increased LR + to 5.56 and post-test probability to 63.0%, indicating improved diagnostic accuracy.

Comparison of cut-off values for SARC-F questionnaires

In addition, the same test was done on SARC-F, SARC-CalF, and SARC-F + EBM to determine the optimal cut-off points. For SARC-F, an optimal cutoff SARC-F ≥ 3 increased sensitivity to 41.0% from 25.6%, but decreased

Table 5 Performance of body assessment at each cutoff point

Cutoff-point	Sensitivity (%)	Specificity (%)	LR +	LR-	Post-test probability (positive, negative)	Youden index
Calf circumference						
Male <						
36	78.8	83.8	4.87	0.25	60.0, 7.0	0.626
36.5	84.9	78.7	3.98	0.19	55.0, 6.0	0.635
37	90.9	77.2	3.99	0.12	55.0, 3.5	0.681[a]
37.5	93.9	69.1	3.04	0.09	49.0, 3.0	0.631
38	100.0	62.5	2.67	0.00	45.0, 0.0	0.625
Female <						
35	73.3	80.0	3.67	0.33	53.0, 9.0	0.533
35.5	80.0	73.0	2.97	0.27	48.0, 8.0	0.530
36	91.1	67.8	2.83	0.13	47.0, 3.9	0.589[a]
36.5	95.6	61.7	2.50	0.07	44.0, 2.0	0.573
37	97.8	55.7	2.20	0.04	41.0, 1.0	0.534
Neck circumference						
Male <						
38	48.8	93.4	7.32	0.55	69.0, 15.0	0.419
38.5	57.6	88.2	4.90	0.48	60.0, 13.0	0.458
39	60.6	85.3	4.12	0.46	56.0, 13.0	0.459
39.5	69.7	78.9	3.27	0.39	50.0, 11.0	0.484[a]
40	72.7	74.3	2.83	0.37	47.0, 10.0	0.470
Female <						
35	55.6	86.9	4.26	0.51	57.0, 14.0	0.425
35.5	64.4	74.7	2.56	0.48	44.0, 13.0	0.392
36	71.1	71.3	2.48	0.41	43.0, 11.0	0.424
36.5	82.2	62.6	2.20	0.28	41.0, 8.0	0.448[a]
37	84.4	59.1	2.07	0.26	39.0, 8.0	0.436
Calf circumference: M < 37; F < 36 Neck circumference: M < 39.5; F < 36.5	73.1	86.9	5.56	0.31	63.0, 9.0	0.600

[a] The maximum of the Youden index

specificity from 86.1% to 75.7% compared to the general population value. The optimal SARC-CalF threshold was ≥10 (sensitivity 61.5%, specificity 90.8%) when compared with the general threshold (SARC-CalF ≥11), which showed a reduced sensitivity of (48.7%), but higher specificity (93.2%). For SARC-F + EBM, the best Youden index threshold was 5 (sensitivity 73.1%, specificity 77.3%), whereas the general population cutoff (SARC-F + EBM ≥12) had lower sensitivity (35.9%), but higher specificity (87.6%). Supplementary Table 1 displays the performance characteristics of SARC-F, SARC-F + EBM, and SARC-CalF, including sensitivity, specificity, false positive rate, and the Youden index.

For SARC-F ≥3, the LR + was 1.69, with a positive post-test probability of 34.0%, indicating limited diagnostic accuracy. SARC-CalF ≥10, had a significantly higher LR + of 6.72, with a post-test probability of 68.0%, suggesting stronger diagnostic performance. For SARC-F + EBM ≥5, the LR + was 3.22, and the positive post-test probability was 50.0%, indicating moderate diagnostic accuracy.

Discussion

The prevalence of sarcopenia is considerable. It affects 23.7% of people with T2DM. A study by Vanitcharoenkul E., et al., found the prevalence of sarcopenia in Thai older adults to be 18.1% [25], lower than in this study involving people with T2DM. Across Asian populations, sarcopenia prevalence varies significantly, with reported rates of 12.5–15.3% in Japan (AWGS2014) [26, 27], 37.3% in Taiwan (AWGS2019) [28], 18.8% in North India (AWGS2019) [29], 15.4% in Iraq (EWGSOP2) [30], and 28.5% in Malaysia (AWGS2014) [31], as shown in supplementary Table 2. These discrepancies may be attributed

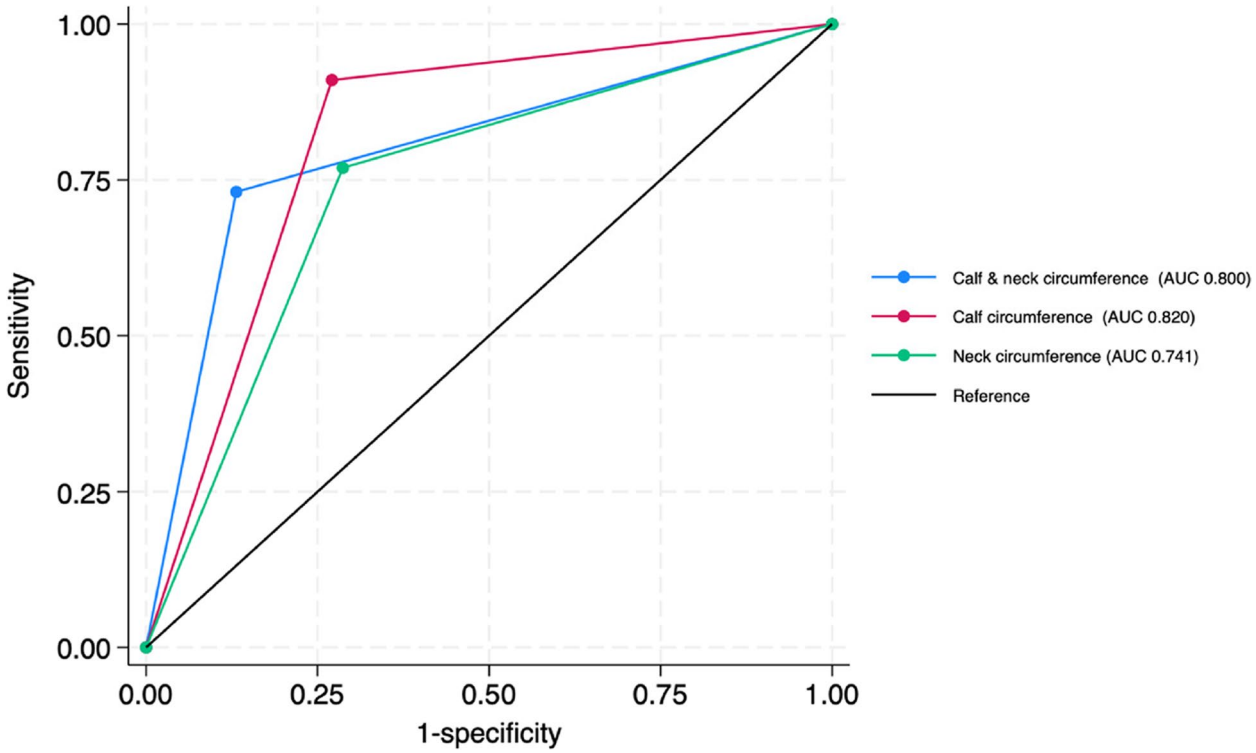

Fig. 4 ROC curve analysis of calf and neck circumferences to discriminate sarcopenia in T2DM patient

to differences in diagnostic criteria, screening methodologies, and population characteristics, emphasising the need for tailored sarcopenia screening in people with T2DM.

Thus, it is essential to ensure early diagnosis using simple and effective sarcopenia screening tools with high sensitivity and acceptable specificity. However, the present study has revealed that despite SARC-F being the first tool for sarcopenia screening in people with T2DM [32], SARC-F has low sensitivity (25.6%) and low diagnostic accuracy (AUC = 0.602) in diagnosing sarcopenia in T2DM. These findings align with previous studies conducted in the Asian population, including people with axial spondylarthritis [33], chronic kidney disease [34], and T2DM inpatients [18]. Due to SARC-F's low sensitivity and specificity, its clinical application is limited. Hence, adjustments to the SARC-F assessment and other possible screening tools must be explored. The poor sensitivity of SARC-F has underscored the need for modifications or alternative screening approaches in both community and hospital settings.

Screening strategies must be tailored to different clinical settings. In community-based settings, screening tools need to prioritise high sensitivity to identify at-risk individuals early, even at the expense of specificity. In hospital outpatient settings, where diagnostic resources and follow-up are available, screening tools must balance sensitivity with specificity to reduce false positives and ensure efficient clinical decision-making.

Several strategies have been proposed to enhance the sensitivity of SARC-F. First, lower the cutoff value to 1 [35]. Similar to our results, SARC-F ≥ 1 showed increased sensitivity and AUC. The second approach combines SARC-F with additional factors like CC, age, or BMI. SARC-CalF has been recommended [23] due to the correlation between muscle mass and CC [36]. Similar to our findings, SARC-CalF has shown increased sensitivity and accuracy in previous studies in people with Parkinson's disease [37], advanced cancer [38], chronic musculoskeletal pain [39], community-dwelling older adults [25, 40–42], and older women [43], even in low-resource settings [44].

The present studies also revealed that SARCF + EBM improved sensitivity and diagnostic accuracy compared to SARC-F alone. Kurita et al., first introduced and validated SARC-F + EBM in 2019, using the AWGS and EWGSOP2 criteria for sarcopenia in a study involving 959 adults with musculoskeletal diseases [24]. The sensitivity of SARC-F + EBM in this study was 35.9%, notably lower than the 77.8% reported by Kurita et al. This difference may be due to variations in BMI among study participants, as an additional 10 points in the SARC-F

+EBM score are allocated for a BMI ≤21. In our study, people with T2DM had higher BMI levels than participants with degenerative diseases in Kurita et al.'s study [24], highlighting the potential need for a lower cutoff score for SARC-F +EBM in people with T2DM, possibly below 12. This is supported by the finding that a SARC-F +EBM score ≥5 achieved the highest Youden index in this study. Furthermore, it is essential to recognise the differences in sarcopenia diagnostic criteria; this study used the AWGS2 criteria, whereas Kurita et al., applied the AWGS criteria. As SARC-F +EBM is a relatively new tool, its validation remains limited to a few studies and specific populations.

The third strategy is to apply calf circumference as an independent screening tool. CC exhibited the highest AUC and LR +at the standard cutoff value. Hence, it could serve as an effective screening tool for sarcopenia in people with T2DM. Furthermore, CC has been associated with low muscle mass [45], low physical performance [46], and sarcopenia [47]. Recent studies have also shown that CC outperforms SARC-CalF [25, 48–50]. As being overweight is one of the risk factors of T2DM, which can mask sarcopenia, the cutoff value of CC in patients with sarcopenia needs to be adjusted. This study proposes <37 cm for males and <36 cm for females as cutoff values for sarcopenia in T2DM patients. These cutoffs were considerably higher than the proposed cutoffs by the AGWS at <34 cm for males and <33 cm for females [23] and by Vanitcharoenkul E., at <33 cm for males and <31 cm for females in Thai older adults [25]. These values also had a higher sensitivity of more than 90% and acceptable specificity compared to the values of the general population.

Neck circumference has also shown a promising sensitivity as a screening tool. A study by Ryo Sato et al., on Japanese elderly presented with several chronic diseases found an association between NC and sarcopenia, proposing cutoff values of 32.8 cm for females and 38.0 cm for males in older adults [21]. However, this study found the values to be much higher in people with T2DM, suggesting a cutoff value of 36.5 cm for females and 39.5 cm for males. Moreover, NC can be more easily measured than other bodily measurements, as the neck is relatively short. This ensures more accuracy in determining the position of measurement. NC measurement is also more advantageous and practical in outpatient settings as it does not require removing outerwear and can be measured in bedridden people with T2DM or those with amputated legs, making it a viable alternative to CC.

Combining CC and NC has also shown high sensitivity, specificity, and a positive likelihood ratio. Combining the measurements showed reduced sensitivity, but increased specificity compared to CC alone. On the other hand, compared to NC alone, the combination exhibited increased sensitivity, but compromised specificity. Nevertheless, this combination resulted in a higher likelihood ratio and positive post-test probability than the measurements individually, proving to be a possible novel outpatient-friendly screening approach for sarcopenia at their optimum cutoff points.

In outpatient settings, where time and resource constraints are critical considerations, the choice of sarcopenia screening tools must balance accuracy, ease of use, and integration into routine care. CC has emerged as the most effective screening measure, with proposed T2DM-specific thresholds enhancing sensitivity and specificity. Tailored strategies, including adjusted cutoff points and combined anthropometric measures, are essential for early sarcopenia detection in people with T2DM. These findings advocate for further validation and implementation of optimised screening tools to mitigate sarcopenia-related risks and improve outcomes.

This study had several limitations. First, the study population was recruited from a single-center tertiary hospital in Thailand, which may limit the generalisability of the findings to other ethnic groups and healthcare settings. Validation in diverse cohorts is necessary to establish the robustness of these findings across varied populations. Second, the proposed new cutoff values for calf and neck circumference require further validation in independent cohorts with sex-specific adjustments before being widely adopted in clinical practice to optimise screening for both men and women. Third, this study was cross-sectional and a longitudinal study would be needed to determine how these screening tools predict the progression of sarcopenia over time and their potential role in clinical decision-making. Additionally, while this study focused on specific anthropometric measures, weight-adjusted assessments were not explored due to their impracticality in routine clinical settings. Future studies could explore the potential for more practical weight-adjusted approaches. Lastly, further research is needed to better understand the relationship between neck circumference and sarcopenia and its potential clinical implications.

Conclusion

This study has underscored the significance of accurate sarcopenia screening among people with T2DM, given the 23.7% prevalence and its association with adverse health outcomes. Since SARC-F, the most commonly used tool, has demonstrated limited sensitivity, alternative methods such as SARC-CalF and SARC-F +EBM have shown improved diagnostic performance. Calf circumference has emerged as the most effective screening tool, offering the highest sensitivity and accuracy at the

proposed T2DM-specific cutoffs. Additionally, neck circumference has been identified as a simple and practical screening measure, particularly suitable for outpatient settings. These findings highlight the importance of optimising sarcopenia screening tools tailored to people with T2DM in outpatient settings to ensure early detection and intervention.

Abbreviations

AGEs	Advanced Glycation End Products
T2DM	Type 2 Diabetes Mellitus
ASM	Appendicular skeletal muscle mass
DXA	Dual-energy X-ray Absorptiometry
BIA	Bioelectrical Impedance Analysis
AWGS	The Asian Working Group for Sarcopenia
BMI	Body Mass Index
CC	Calf Circumference
NC	Neck Circumference

Supplementary Information

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Supplementary Material 1

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Authors' contributions
O.L. and P.S. were involved in the conception of the study. O.L., T.L., and P.S. conducted the participant recruitment and collected data. O.L. and P.S. wrote and reviewed the manuscript. N.S. and A.B. did the final reviews. All authors read and approved the final manuscript.

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Data availability
The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The Royal Thai Army Institutional Board Review approved the study under reference R080h/66. It was performed in accordance with the Declaration of Helsinki, and all participants gave written informed consent before participating.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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