

Factors Associated With Locomotive Syndrome Severity Among Community-Dwelling Older Adults With Type 2 Diabetes: A Cross-Sectional Analytical Study

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Abstract

Background: Locomotive syndrome (LS) threatens mobility and functional independence among older adults with type 2 diabetes mellitus (T2DM). Evidence remains limited regarding multilevel factors associated with LS severity in community-based primary care settings.

Objective: To examine social ecological model aligned factors associated with LS severity among community-dwelling older adults with T2DM.

Methods: A cross-sectional analytical study was conducted in primary care units and community health centers in Suphan Buri province, Thailand. Multistage sampling recruited 253 adults aged 60 years or older with physician-diagnosed T2DM. LS severity was assessed using the 25-item Geriatric Locomotive Function Scale. Predictors included demographic and clinical characteristics, nutritional status, health literacy, family and social support, patient-provider communication (PPC), and access to healthcare services. Pearson correlation and hierarchical multiple linear regression were used.

Results: Participants had a mean (SD) age of 68.5 (6.2) years, and 64.8% were female. Mean (SD) GLFS-25 score was 32.5 (14.8). In bivariate analyses, LS severity was positively correlated with neuropathy risk, age, and polypharmacy and negatively correlated with nutritional status, health literacy, access, PPC, and family and social support. The final hierarchical model was statistically significant ($R = 0.568$; $R^2 = 0.323$; adjusted $R^2 = 0.300$; $F[8,244] = 14.55$; $P < .001$). Greater LS severity was associated with neuropathy risk ($B = 6.47$; $\beta = 0.22$; $P < .001$), older age ($B = 0.41$; $\beta = 0.17$; $P = .002$), and polypharmacy ($B = 0.66$; $\beta = 0.14$; $P = .010$). Better nutritional status was associated with lower LS severity ($B = -1.41$; $\beta = -0.20$; $P < .001$).

Conclusions: LS severity was associated mainly with clinical burden and nutritional status. Causal and temporal relationships cannot be inferred from these cross-sectional data.

Keywords: Locomotive syndrome, Sarcopenia, Type 2 diabetes mellitus, Health literacy, Older adults, Primary care

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Introduction

Population aging is advancing rapidly worldwide, including in Thailand, and is occurring alongside an increasing burden of chronic disease and functional limitation in later life. Type 2 diabetes mellitus (T2DM) is of particular concern because its long-term metabolic, vascular, and inflammatory consequences are associated with impaired muscle strength, balance, and physical endurance.^{1,2} Evidence further suggests a bidirectional relationship between diabetes and sarcopenia, insulin resistance and chronic inflammation may reduce muscle protein synthesis and compromise muscle quality, whereas declining muscle mass may adversely affect glucose metabolism and glycemic control.³⁻⁵ These interrelated conditions may contribute to mobility limitation and loss of physical independence, particularly among older adults who must simultaneously manage multimorbidity, polypharmacy, dietary restrictions, and complex self-care regimens.^{6,7} Consequently, diabetes-related functional decline may increase the need for continuing primary care, family assistance, and community-based support.

Locomotive syndrome (LS) provides a clinically relevant framework for identifying mobility-related decline before severe dependency becomes established. First proposed by the Japanese Orthopedic Association in 2007, LS refers to reduced mobility resulting from impairment of the musculoskeletal system involved in standing, walking, and maintaining physical independence.^{4,8} Unlike constructs that primarily describe established disability, LS captures a continuum of functional difficulty and supports the early recognition of mobility problems. In clinical and community research, LS is commonly assessed using the 25-item Geriatric Locomotive Function Scale (GLFS-25), which evaluates pain, activities of daily living, social participation, and movement-related limitations.^{8,9} The GLFS-25 classifies LS severity as stage 0 (< 7), stage 1 (7-15), stage 2 (16-24), and stage 3 (≥ 24), with higher scores indicating greater mobility-related impairment.¹⁰ In the present study, the GLFS-25 score is therefore interpreted as an indicator of LS severity rather than disease progression.

Existing evidence indicates that LS severity among older adults is associated with a combination of demographic, clinical, behavioral, and contextual characteristics. Reduced mobility is linked to falls, frailty, dependency, and increased caregiving needs, although the magnitude and pattern of these relationships vary across populations and care settings.¹¹ Among older adults with T2DM, neuropathy, obesity, cardiovascular disease, musculoskeletal pain, and other diabetes-related complications may coexist and are associated with poorer gait, lower physical activity, and reduced participation in daily life.^{12,13} However, biomedical conditions alone may not adequately explain differences in LS severity. Nutritional status and health literacy may influence the capacity to maintain physical function and perform diabetes self-management, while social support, patient-provider communication (PPC), and access to healthcare may shape opportunities to obtain assistance, understand treatment recommendations, and remain engaged with primary care.^{14,15} Lower educational attainment may further constrain access to understandable health information and confidence in navigating complex healthcare demands, although education may operate through health literacy, communication, and service accessibility rather than as an isolated determinant.¹⁶ Conversely, supportive family relationships, responsive communication, and accessible healthcare services may represent modifiable resources associated with lower functional burden.¹⁷

Despite growing interest in LS, previous studies have predominantly emphasized individual-level risk factors, musculoskeletal impairments, and adverse outcomes. Evidence remains limited regarding the combined contribution of modifiable factors operating at

interpersonal, healthcare-service, and community levels, particularly among community-dwelling older adults with T2DM and lower educational attainment.³⁻⁵ Many studies have examined clinical characteristics separately from health literacy, nutritional status, social support, communication, or access to healthcare, making it difficult to determine how these factors are related when considered within a common theoretical framework. Moreover, evidence from community-based primary care settings remains comparatively sparse. This gap is important because LS severity may reflect not only an individual's disease burden or self-care capacity but also the social and service environments in which diabetes management and daily mobility occur.

The social ecological model (SEM) is therefore appropriate for guiding this study because it conceptualizes health outcomes as arising from interactions across multiple levels rather than from individual behavior alone. McLeroy et al¹⁸ proposed that health is shaped by intrapersonal, interpersonal, organizational, community, and policy-level determinants. Within the present study, the individual level encompasses demographic and clinical characteristics, nutritional status, and health literacy; the interpersonal level includes family and social support; and the healthcare or organizational level includes PPC, continuity of care, and access to healthcare services.¹⁹⁻²² At the broader community level, transportation, geographical accessibility, supportive environments, and available community resources may influence whether older adults can attend healthcare services and sustain mobility-related behaviors. Policy and health-system arrangements may also determine the availability and coordination of age-friendly, diabetes-responsive, and function-oriented care.²³⁻²⁶ Using the SEM therefore allows LS severity to be examined as a multilevel issue shaped by the interaction of personal capacity, social relationships, healthcare delivery, and community conditions.

Clarifying these multilevel associations has relevance for healthy-aging policy and integrated primary care for older adults with T2DM. Early identification of factors associated with LS severity may help nurses and primary care teams recognize individuals who require nutritional assessment, tailored health communication, family involvement, mobility support, or improved access to services. Such evidence may also inform feasible community-based nursing interventions while avoiding the assumption that functional decline results solely from individual behavior. Accordingly, this cross-sectional analytical study aimed to examine individual, interpersonal, and healthcare-related factors associated with LS severity among community-dwelling older adults with T2DM, guided by the SEM.

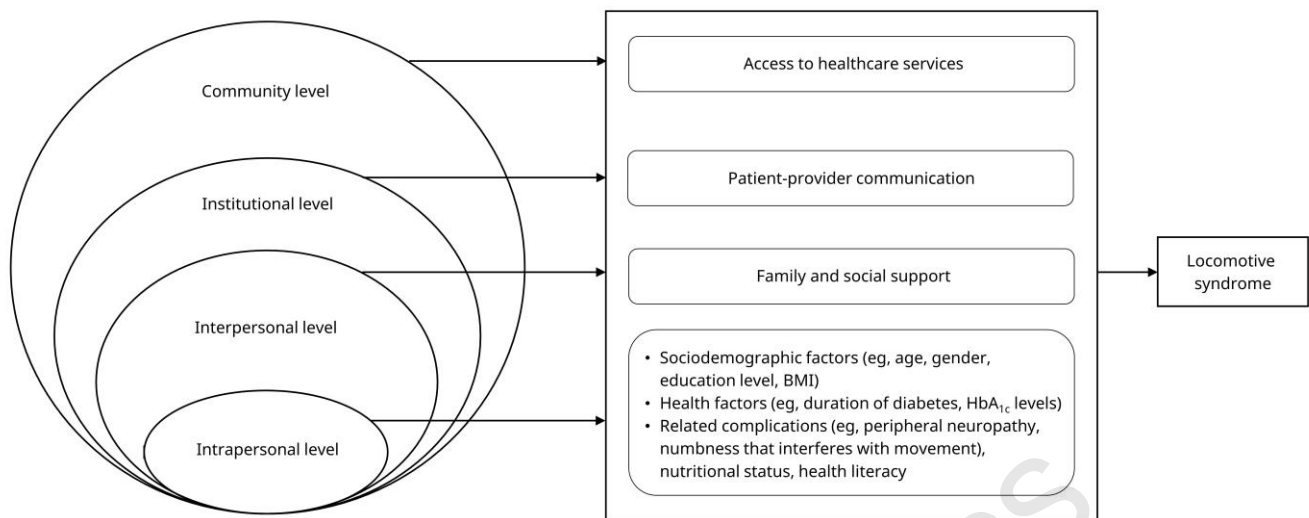
Methods

Study Design and Setting

This cross-sectional analytical study grounded in the SEM, which conceptualizes health outcomes as being associated with interacting intrapersonal, interpersonal, institutional or healthcare-related, and community-level factors (Figure 1).^{18, 27} The study was carried out in primary care units (PCUs) and community health centers in Suphan Buri province, Thailand.

Multistage sampling was employed. Districts were selected at the first stage, followed by the selection of subdistrict health facilities that provided chronic disease and older adult services. Within each participating PCUs, the number of participants was allocated proportionately according to the size of its eligible T2DM registry. Eligible participants were subsequently recruited from clinic registries during scheduled clinic visits. This approach was intended to obtain participants from primary care settings serving older adults with different community and healthcare-access characteristics.

Figure 1. Conceptual Framework of the Study



Abbreviations: BMI, body mass index; HbA_{1c}, hemoglobin A_{1c}.

Participants and Sampling

The target population comprised community-dwelling older adults with T2DM. Eligibility criteria were age 60 years or older, physician-diagnosed T2DM for at least one year, residence in the community, and ability to communicate in Thai and provide informed consent. Caregiver assistance was permitted when needed for communication or clarification of factual information; however, caregivers did not complete subjective measures on behalf of participants. Individuals with severe mobility-limiting complications, including stroke with substantial residual disability, lower-limb amputation, or a high-risk diabetic foot condition, were excluded because these conditions could independently determine mobility status. Individuals with suspected severe cognitive impairment that could affect informed consent or the reliability of questionnaire responses were also excluded.

Cognitive ability was assessed during eligibility screening using the Mini-Mental State Examination-Thai 2002 (MMSE-Thai 2002).²⁸ The assessment was administered by trained research nurses before questionnaire administration. Education-specific cutoff scores were applied: ≤ 14 of 23 points for participants who had not attended school or were unable to read and write, ≤ 17 of 30 points for those with primary education, and ≤ 22 of 30 points for those with education above the primary level. Participants scoring at or below the applicable cutoff were considered to have suspected cognitive impairment and were not enrolled in the study. They were referred to the responsible PCU clinician for further assessment in accordance with routine local procedures.

The sample size for the planned multivariable analysis was estimated using G*Power, based on the number of predictors specified a priori in the conceptual model (22 predictors), a medium effect size of $f^2 = 0.15$, a 2-sided $\alpha = .05$, and a statistical power of 0.95. This calculation yielded a minimum sample of 230 participants.²⁹ To allow for an anticipated 10% rate of nonresponse or incomplete data, the recruitment target was calculated using the formula $n(\text{final}) = n/(1-r)$; $230/(1-0.10) = 255.56$, which was rounded up to 256 participants. Ultimately, complete data from 253 participants were available for analysis.

Although the achieved sample was 3 participants below the adjusted recruitment target, it remained above the minimum analytic requirement of 230.

The final analytic sample was proportionally distributed across 4 PCUs; Ban Long Tong ($n = 58$), Bo Suphan ($n = 86$), Chedi ($n = 46$), and Krachan ($n = 63$). Data were collected from December 2025 to February 2026. Trained research nurses screened clinic registries, assessed eligibility, obtained written informed consent, and administered the questionnaires in a private setting.

Measures and Social Ecological Model Domains

Measures were organized according to the SEM.¹⁸ Guided by theory and previous evidence, the study examined factors at intrapersonal, interpersonal, institutional or healthcare-related, and community levels, with the continuous GLFS-25 score representing LS severity as the dependent variable. Data were collected using a structured questionnaire package comprising researcher-developed demographic and clinical items together with standardized instruments that had previously been translated, culturally adapted, or used in Thai populations.

Intrapersonal Level Measures

Individual sociodemographic and clinical characteristics were collected using a structured form developed by the research team. The form contained 15 categorical and short-answer items addressing sex, age, education, household income, duration of diabetes, hemoglobin A_{1c} (HbA_{1c}), hypertension, kidney disease, heart disease, treatment modality, complementary and alternative medicine (CAM) use, analgesic use, number of current medications, distal numbness suggestive of peripheral neuropathy, movement-limiting joint pain, and falls during the previous year. Relevant clinical data, including HbA_{1c}, diagnoses, and medication information, were verified against medical records when available. Content relevance and clarity were evaluated by the expert panel.

Nutritional status was assessed using the Mini Nutritional Assessment-Short Form (MNA-SF), originally developed by Rubenstein et al³⁰ and available in a Thai version through the Ministry of Public Health.³¹ The MNA-SF comprises 6 items assessing reduced food intake, recent weight loss, mobility, recent psychological stress or acute illness, neuropsychological problems, and body mass index (BMI). Each item has an item-specific weighted response, and item scores are summed to produce a total score ranging from 0 to 14. Scores of 12-14 indicate normal nutritional status, scores of 8-11 indicate risk of malnutrition, and scores of 0-7 indicate malnutrition. Calf circumference was used as the recommended alternative when BMI could not be determined. Higher scores indicate better nutritional status. The expert panel reviewed the linguistic clarity and contextual appropriateness of the Thai items, without altering the established scoring structure. In the pilot sample, the internal-consistency coefficient was Cronbach α of 0.89.

Health literacy was assessed using the 14-item Health LiteracyScale developed from the functional, communicative, and critical health literacy framework of Ishikawa et al³² and adapted for Thai settings by Noppakraw et al.³³ The instrument comprises 5 functional health literacy items, 5 interactive or communicative health literacy items, and 4 critical health literacy items. Items are rated on a 4-point response scale. Negatively worded functional health literacy items were reverse-scored before the item scores were summed. Total scores range from 14 to 56, with higher scores indicating greater overall health literacy.

The original 3-domain instrument demonstrated Cronbach α coefficients of 0.83 for functional health literacy, 0.85 for communicative health literacy, and 0.76 for critical health literacy, whereas the cited Thai adaptation reported an overall coefficient of approximately 0.91.³³ The expert panel examined semantic equivalence, clarity, and relevance to older Thai adults with T2DM. In the pilot sample for the present study, Cronbach α was 0.83 for the total scale.

Interpersonal Level Measure

Family and social support was measured using Ruankham's questionnaire,³⁴ which was developed from House's social support framework.³⁵ The 16-item instrument covers emotional, informational, appraisal, and tangible support. Each item is rated from 1 to 4, and item scores are summed to yield a total score ranging from 16 to 64. Higher scores indicate greater perceived family and social support. The previous Thai study reported Cronbach α of approximately 0.86. The expert panel reviewed item relevance and clarity for community-dwelling older adults with T2DM, and all retained items met the predetermined content-validity criterion. Cronbach α in the pilot sample was 0.82.

Institutional or Healthcare Level Measure

PPC was assessed using the 9-item PPC Scale originally developed by Xu²⁷ and translated and culturally adapted for Thai patients by Pinprapapan et al.³⁶ The instrument measures general clarity of communication, explanation of care and treatment, listening, and responsiveness to patient concerns. Items are rated on a 4-point scale ranging from 1 to 4. Negatively worded items are reverse-scored, and the item scores are summed to produce a total score ranging from 9 to 36. Higher scores indicate better perceived communication with healthcare providers. The original scale reported a reliability coefficient of 0.74, whereas the Thai study reported Cronbach α of 0.77. The expert panel reviewed the clarity and contextual suitability of the wording for older adults receiving diabetes care in PCUs. In the pilot sample for the present study, Cronbach α was 0.80.

Community Level Measure

Access to healthcare services was assessed using a 15-item scale adapted from Khajornumrongcherdkul et al.³⁷ The instrument measures 4 dimensions of perceived access: acceptability, geographical accessibility, availability, and accommodation or organization of services. Each item is rated on a 5-point Likert-type scale ranging from 1 to 5. Item scores are summed to yield a total score ranging from 15 to 75, with higher scores indicating better perceived access to healthcare services. The source instrument reported Cronbach α of 0.91. The expert panel evaluated whether the items reflected access conditions relevant to rural and community-based primary care in Suphan Buri province. Cronbach α in the pilot sample was 0.87.

Outcome Measure

LS severity was measured using the GLFS-25, developed by Seichi et al.¹¹ and translated and psychometrically tested in Thai by Buntham et al.³⁸ The GLFS-25 assesses body pain, movement-related difficulty, activities of daily living, social functioning, and mobility-related psychological concerns during the previous month. Each item is scored from 0, indicating no impairment, to 4, indicating severe impairment. Item scores are summed to produce a total score ranging from 0 to 100, with higher scores indicating

greater LS severity. The continuous total score was used as the primary outcome in the regression analysis. The Thai version demonstrated excellent content validity, with a reported content validity index of 1.00, and excellent internal consistency, with Cronbach α ranging from 0.94 to 0.95. In the pilot sample for the present study, Cronbach α was 0.92.

Instrument Development and Validation

To ensure that the measurement package was appropriate for community-dwelling older adults with T2DM in Thailand, a systematic review and validation process was applied to the researcher-developed items and the contextually adapted components of the standardized instruments. The questionnaire package comprised 7 parts: the sociodemographic and clinical form, the MNA-SF, the Thai-adapted Health Literacy Scale, the Family and Social Support Questionnaire, the Thai PPC Scale, the Access to Healthcare scale, and the Thai GLFS-25.

Content validity was evaluated by a panel of 5 specialists with expertise in gerontological nursing, community and primary care nursing, internal medicine, rehabilitation or orthopedics, and quantitative research. The panel assessed item relevance, clarity, and correspondence with the study objectives and SEM domains using the item-objective congruence (IOC) method described by Streiner et al.³⁹ Each item was evaluated against a predetermined IOC criterion of 0.66. Items with IOC values below 0.66 were revised or removed, and all items retained in the final questionnaire achieved an IOC of at least 0.66. Established scoring procedures and domain structures of the standardized instruments were not altered.

The revised questionnaire package was pilot-tested with 30 community-dwelling older adults with physician-diagnosed T2DM who received care outside the main study sites. The pilot test evaluated item clarity, cultural appropriateness, feasibility of interviewer administration, completion time, and respondent burden. Internal consistency was estimated separately for each multi-item scale rather than for the questionnaire package as a whole. Cronbach α coefficients obtained from the pilot sample were 0.89 for the MNA-SF, 0.83 for the Health Literacy Scale, 0.82 for the Family and Social Support Questionnaire, 0.80 for the PPC Scale, 0.87 for the Access to Healthcare Services Scale, and 0.92 for the GLFS-25 Scale. Coefficients of 0.70 or higher were considered acceptable; however, each coefficient was interpreted in relation to the number of items, dimensional structure, and intended measurement purpose of the corresponding instrument.

Data Collection Procedures

Data were collected between December 2025 and February 2026 after approval was obtained from the Human Research Ethics Committee of the Suphan Buri Provincial Public Health Office and administrative permission was granted by the participating PCUs. A standardized recruitment and data collection protocol was used to promote procedural consistency and protect participants' rights. Potential participants were identified from T2DM registries with assistance from local health personnel and village health volunteers. After receiving a clear explanation of the eligibility-screening process, potential participants were assessed using the study criteria and MMSE-Thai 2002. Eligible individuals were then informed in plain Thai language about the study purpose, procedures, expected time commitment, voluntary participation, confidentiality, potential inconvenience, and right to withdraw without affecting their healthcare before written informed consent was obtained.

Data were collected through face-to-face, interviewer-administered questionnaires and standardized assessments. Anthropometric measurements and relevant clinical

information were verified from medical records when available. Interviews were conducted in private areas of the participating clinics or during home visits when appropriate. Each interview required approximately 30-45 minutes. Participants were encouraged to proceed at a comfortable pace and could request a break, postpone a section, or discontinue participation at any time. Research nurses observed participants for fatigue or discomfort and offered short rest periods when needed.

All completed instruments were reviewed for completeness on the day of data collection. Data were coded, deidentified, and double-entered to reduce data-entry errors. The participant identification file was stored separately from the analytical dataset. Electronic data were maintained in password-protected files accessible only to the principal investigator and authorized members of the research team. Paper documents were stored in a locked cabinet in a restricted-access office. Data will be retained for 5 years and then securely destroyed in accordance with institutional data-governance requirements.

Statistical Analysis

Participant characteristics and study variables were summarized using means (SDs) for approximately normally distributed continuous variables, medians and interquartile ranges (IQRs) for skewed continuous variables, and frequencies and percentages for categorical variables. Analyses were performed using JASP version 0.96 (JASP Team).

Before regression modeling, data quality, distributions, and model assumptions were examined. Normality of model residuals was evaluated using histograms, normal Q-Q plots, and the Shapiro-Wilk test. Linearity and homoscedasticity were assessed using plots of standardized residuals against standardized predicted values. Independence of errors was evaluated using the Durbin-Watson statistic, with values close to 2 considered acceptable. Multicollinearity was evaluated using tolerance and variance inflation factor (VIF) values; tolerance values greater than 0.20 and VIF values below 5 were considered evidence against problematic multicollinearity. Standardized residuals, leverage values, and Cook's distance were examined to identify potentially influential observations.^{40, 41} The observed ranges of the diagnostic statistics and the results of the residual assessment were reported rather than stating only that assumptions had been examined. The extent and pattern of missing data were evaluated before analysis. Complete data were available for the 253 participants included in the final analytic sample; therefore, no mean substitution or other single-value imputation was performed.

Bivariate associations between each predictor and the continuous GLFS-25 score were examined using Pearson correlation coefficients for continuous variables, independent-samples *t* tests for dichotomous variables, and one-way analysis of variance (ANOVA) for categorical variables with more than 2 groups. Spearman rank correlation, Mann-Whitney *U* tests, or Kruskal-Wallis tests were used when distributional or measurement-level assumptions for parametric analyses were not adequately met. Categorical predictors included in the multivariable model were dummy-coded using clinically meaningful reference categories.

A hierarchical multiple linear regression analysis was conducted to examine factors associated with LS severity. Predictor entry was determined a priori from the SEM and previous evidence rather than by automated statistical selection. In Block 1, demographic and clinical covariates were entered to account for background differences. In Block 2, modifiable intrapersonal factors, including nutritional status and health literacy, were added. In Block 3, the interpersonal-level social support variable was entered. In Block 4, PPC and

access to healthcare services were added to represent institutional or healthcare-related and community-level influences. This sequence permitted assessment of the additional variance in LS severity explained by each ecological level after accounting for variables entered in the preceding blocks.

For each regression model, unstandardized coefficients (B), standard errors, standardized coefficients (β), 95% CIs, and 2-sided P values were reported. Overall model performance was described using R^2 , adjusted R^2 , the model F statistic, and its associated P value. Changes in explanatory power between successive blocks were reported using ΔR^2 and the F -change statistic. Tolerance and VIF values were reported for predictors in the final model. A 2-sided P value of less than .05 was considered statistically significant.^{40, 41} Because the data were cross-sectional, regression coefficients were interpreted as adjusted associations and not as causal, preventive, or longitudinal effects.

Results

Participant Characteristics

The mean (SD) age was 68.5 (6.2) years, and most participants were female (64.8%). Nearly three-quarters had no formal education or primary school education (72.3%), and more than half reported insufficient income (55.3%). Participants had lived with T2DM for the mean (SD) of 8.4 (4.5) years. Based on the 10-g monofilament examination, 53.4% screened positive for peripheral neuropathy risk; among those screening positive, 41.5% were categorized as low risk and 58.5% as moderate risk. Comorbidities were common (81.4%), with hypertension (50.0%) and dyslipidemia (43.2%) most frequently reported among those with comorbidity. Most participants were treated with oral agents (70.4%), while 18.6% used combined oral and injectable therapy. Use of CAM was reported by 56.9%, most commonly vitamins/supplements (79.9% among CAM users). Nonsteroidal anti-inflammatory drug (NSAID) use was reported by 44.3%. The mean (SD) number of current medications was 6.8 (3.2), with mean (SD) HbA_{1c} of 7.6 (1.3)% and mean (SD) BMI of 24.9 (3.4) kg/m² (Table 1).

Social Ecological Measures

Participants showed relatively favorable nutritional status, with a mean (SD) nutritional status score of 11.2 (2.1), indicating that most were in the normal or at-risk range rather than malnourished. Health literacy was moderate (mean [SD], 38.5 [7.8]), consistent with the low educational attainment observed in the sample. Family and social support was moderate to high (mean [SD], 48.6 [8.5]), suggesting that many participants perceived meaningful support across emotional, informational, appraisal, and tangible domains. PPC was generally positive (mean [SD], 27.4 [4.2]), while access to healthcare services was moderate to good (mean [SD], 46.8 [6.9]). The mean (SD) LS score was 32.5 (14.8), indicating overall mild-to-moderate LS severity with considerable individual variability (Table 2).

Relationships Between Variables and Locomotive Syndrome

Greater LS severity was positively associated with peripheral neuropathy risk ($r = 0.34$, $P < .001$), older age ($r = 0.30$, $P < .001$), and polypharmacy ($r = 0.27$, $P < .001$). Smaller but significant positive correlations were also observed for diabetes duration ($r = 0.19$, $P < .01$), HbA_{1c} ($r = 0.18$, $P < .01$), and BMI ($r = 0.14$, $P < .05$). In contrast, lower LS severity was associated

with better nutritional status ($r = -0.36$, $P < .001$), higher health literacy ($r = -0.28$, $P < .001$), better access to healthcare services ($r = -0.26$, $P < .001$), stronger PPC ($r = -0.24$, $P < .001$), and greater family and social support ($r = -0.20$, $P < .01$) (Table 3).

Table 1. Demographic and Clinical Characteristics of Participants

Characteristic	No. (%)
Age, mean (SD), y	68.5 (6.2)
Gender	
Male	89 (35.2)
female	164 (64.8)
Education level	
No formal education/primary school	183 (72.3)
Secondary school or higher	70 (27.7)
Income sufficiency	
Sufficient	113 (44.7)
Insufficient	140 (55.3)
Duration of T2DM, mean (SD), y	8.4 (4.5)
Peripheral neuropathy risk (10-g monofilament diabetic foot examination)	
No	118 (46.6)
Yes	135 (53.4)
Low risk (among "yes")	56 (41.5)
Moderate risk (among "yes")	79 (58.5)
Comorbidities (other than diabetes)	
None	47 (18.6)
Present (multiple responses allowed)	206 (81.4)
Hypertension	103 (50.0)
Dyslipidemia	89 (43.2)
Chronic kidney disease	34 (16.5)
Gout	13 (6.3)
Heart disease	9 (4.4)
Other (eg, asthma, lung disease)	14 (6.8)
Current diabetes treatment	
Oral agents	178 (70.4)
Injectable therapy	28 (11.1)
Both oral and injectable therapy	47 (18.6)
Use of CAM	
No	109 (43.1)
Yes (multiple responses allowed)	144 (56.9)
Herbal medicines	29 (20.1)
Vitamins/supplements	115 (79.9)
Massage/herbal compress	67 (46.5)
Acupuncture/foot reflexology	86 (59.7)
Other (eg, yoga, meditation therapy)	23 (16.0)

Table 1. Demographic and Clinical Characteristics of Participants (Continued)

Characteristic	No. (%)
Use of NSAIDs	
Yes	112 (44.3)
No	141 (55.7)
Number of current medications, mean (SD)	6.8 (3.2)
HbA _{1c} , mean (SD), %	7.6 (1.3)
BMI, mean (SD), kg/m ²	24.9 3.4

Abbreviations: BMI, body mass index; CAM, complementary and alternative medicines; HbA_{1c}, hemoglobin A_{1c}; NSAIDs, nonsteroidal anti-inflammatory drugs; T2DM, type 2 diabetes.

Table 2. Descriptive Statistics of Social Ecological Model Measures

Measure	Scale Range	Mean (SD)	95% CI
Nutritional status (MNA-SF)	0-14	11.2 (2.1)	10.94-11.46
Health literacy (total score)	14-56	38.5 (7.8)	37.54-39.46
Family and social support (total score)	16-64	48.60 (8.5)	47.55-49.65
Patient-provider communication (total score)	9-36	27.40 (4.2)	26.88-27.92
Access to healthcare services (total score)	15-75	46.80 (6.9)	45.95-47.65
LS severity (GLFS-25 total)	0-100	32.50 (14.8)	30.67-34.33

Abbreviations: GLFS-25, 25-question Geriatric Locomotive Function Scale; LS, Locomotive syndrome; MNA-SF, Mini Nutritional Assessment-Short Form.

Table 3. Pearson Correlations Among Social Ecological Model Predictors and Locomotive Syndrome Severity

Variable	1	2	3	4	5	6	7	8	9	11	12
LS severity	1.00										
Nutritional status	-0.36***	1.00									
Health litera	-0.28***	0.22***	1.00								
Family and social support	-0.20**	0.18**	0.25***	1.00							
Patient-provider communication	-0.24***	0.12*	0.30***	0.22***	1.00						
Access to healthcare services	-0.26***	0.17**	0.34***	0.20**	0.36***	1.00					
Age	0.30***	-0.20**	-0.15*	-0.08	-0.10	-0.12*	1.00				
Duration of T2DM	0.19**	-0.10	-0.08	-0.04	-0.06	-0.05	0.26***	1.00			
HbA _{1c}	0.18**	-0.16**	-0.12*	-0.05	-0.10	-0.14*	0.06	0.12*	1.00		
BMI	0.14*	-0.18**	-0.06	-0.03	-0.04	-0.05	-0.05	0.02	0.10	1.00	
Neuropathy risk (1 = yes)	0.34***	-0.22***	-0.11	-0.06	-0.09	-0.10	0.10	0.08	0.16**	0.07	1.00
Polypharmacy	0.27***	-0.12*	-0.10	-0.06	-0.08	-0.09	0.18**	0.16**	0.12*	0.05	0.20**

Abbreviations: BMI, body mass index; HbA_{1c}, hemoglobin A_{1c}; T2DM, type 2 diabetes.

* $P < .05$

** $P < .01$

*** $P < .001$

Factors Associated With Locomotive Syndrome Severity

Hierarchical multiple regression was used to examine SEM-aligned factors associated with LS severity (Table 4). Variables were entered in theoretically specified blocks rather than selected through an automated stepwise procedure. Biological and clinical factors entered in Block 1, including age, neuropathy risk, and polypharmacy, explained 21.4% of the variance in LS severity ($R^2 = 0.214$, adjusted $R^2 = 0.205$, $\Delta R^2 = 0.214$, $P < .001$). In this block, older age ($B = 0.41$, $\beta = 0.17$, $P = .002$), neuropathy risk ($B = 6.47$, $\beta = 0.22$, $P < .001$), and polypharmacy ($B = 0.66$, $\beta = 0.14$, $P = .010$) were associated with higher GLFS-25 scores.

Adding modifiable intrapersonal factors in Block 2, including nutritional status and health literacy, increased the explained variance to 29.7% ($R^2 = 0.297$, adjusted $R^2 = 0.283$, $\Delta R^2 = 0.083$, $P < .001$). Better nutritional status was independently associated with lower LS severity ($B = -1.41$, $\beta = -0.20$, $P < .001$), whereas health literacy showed a negative but nonsignificant association after adjustment for the clinical variables and nutritional status ($B = -0.18$, $\beta = -0.10$, $P = .102$).

In Block 3, family and social support and PPC were added as interpersonal and healthcare communication factors. This block produced a small but statistically significant increase in explained variance ($R^2 = 0.316$, adjusted $R^2 = 0.296$, $\Delta R^2 = 0.019$, $P = .034$). However, neither family and social support ($B = -0.11$, $\beta = -0.07$, $P = .238$) nor PPC ($B = -0.32$, $\beta = -0.09$, $P = .119$) remained independently associated with LS severity in the fully adjusted model.

Access to healthcare services was entered in Block 4 as a healthcare-access factor. The final model was statistically significant and explained 32.3% of the variance in LS severity ($R = 0.568$, $R^2 = 0.323$, adjusted $R^2 = 0.300$, $F[8, 244] = 14.55$, $P < .001$). Access to healthcare services showed a negative but nonsignificant association with LS severity after adjustment for the preceding blocks ($B = -0.20$, $\beta = -0.09$, $P = .122$). Multicollinearity was not evident, with VIF values ranging from 1.08 to 1.25.

The full SEM-guided predictive model for LS severity can be represented as follows: LS severity score_i = $\beta_0 + 0.41(\text{Age}) + 6.47(\text{Neuropathy risk}) + 0.66(\text{Polypharmacy}) - 1.41(\text{Nutritional status}) - 0.18(\text{Health literacy}) - 0.11(\text{Family and social support}) - 0.32(\text{Patient-provider communication}) - 0.20(\text{Access to healthcare services}) + \epsilon_i$, where neuropathy risk is coded as 1 = yes and 0 = no. Interpreting the unstandardized coefficients provides practical meaning. Each additional year of age was associated with a 0.41-point higher GLFS-25 score, and participants with neuropathy risk had GLFS-25 scores 6.47 points higher than those without neuropathy risk, after adjustment for other variables. Each additional medication was associated with a 0.66-point higher GLFS-25 score. In contrast, each 1-point increase in nutritional status was associated with a 1.41-point lower GLFS-25 score. Although health literacy, family and social support, PPC, and access to healthcare services showed associations in the expected negative direction, their independent associations were not statistically significant in the fully adjusted model. These findings suggest that their roles may overlap with clinical burden and nutritional status or may operate through indirect pathways not captured by multiple linear regression.

Table 4. Hierarchical Multiple Regression Predicting Locomotive Syndrome Severity

Block/Predictor	B	SE	95% CI	β	P	VIF
Block 1: Biological and Clinical Factors						
Age	0.41	0.13	0.15 to 0.67	0.17	.002	1.08
Neuropathy risk (yes = 1)	6.47	1.63	3.25 to 9.69	0.22	< .001	1.09
Polypharmacy	0.66	0.25	0.16 to 1.16	0.14	.010	1.08
Block 1 fit	$R^2 = 0.214$; adjusted $R^2 = 0.205$; $\Delta R^2 = 0.214$; $P < .001$					
Block 2: Modifiable Intrapersonal Factors						
Nutritional status	-1.41	0.40	-2.20 to -0.63	-.20	<.001	1.15
Health literacy	-0.18	0.11	-0.40 to 0.04	-.10	.102	1.25
Block 2 fit	$R^2 = 0.297$; adjusted $R^2 = 0.283$; $\Delta R^2 = 0.083$; $P < .001$					
Block 3: Interpersonal and Healthcare Communication Factors						
Family and social support	-0.11	0.10	-0.31 to 0.08	-.07	.238	1.12
Patient-provider communication	-0.32	0.21	-0.73 to 0.08	-.09	.119	1.22
Block 3 fit	$R^2 = 0.316$; adjusted $R^2 = 0.296$; $\Delta R^2 = 0.019$; $P = .034$					
Block 4: Healthcare Access Factor						
Access to healthcare services	-0.20	0.13	-0.45 to 0.05	-.09	.122	1.25
Final model fit	$R = 0.568$; $R^2 = 0.323$; adjusted $R^2 = 0.300$; $P < .001$					

Abbreviations: β , standardized coefficient; B, unstandardized coefficient; SE, standard error; VIF, variance inflation factors.

Discussion

This cross-sectional analytical study examined factors associated with LS severity among community-dwelling older adults with T2DM receiving care in primary care settings in Suphan Buri province, Thailand. The SEM was used as the conceptual framework to organize biological, intrapersonal, interpersonal, healthcare-related, and access-related factors.^{18, 27} The findings should first be interpreted in relation to the participant profile. The sample was predominantly female, with a mean age of 68.5 years and an average diabetes duration of 8.4 years. Most participants had no formal education or only primary education, and more than half reported insufficient income. Comorbidity was common, particularly hypertension and dyslipidemia, and more than half screened positive for peripheral neuropathy risk. These characteristics indicate that LS severity occurred within a clinically complex population marked by aging, chronic disease burden, limited educational resources, and multiple self-management demands.

The relatively small proportion of male participants deserves attention. This pattern may reflect local primary care attendance, population structure, or gender-related differences in health-seeking behavior; however, these explanations were not directly tested in the present study. Therefore, the findings should be generalized to older men with T2DM cautiously. The frequent use of multiple medications, NSAIDs, and CAM further suggests that many participants were managing overlapping symptoms, chronic conditions, and treatment decisions. This context is important because mobility difficulty in older adults with T2DM may not arise from a single pathway, but from the cumulative interaction of diabetes complications, musculoskeletal symptoms, medication burden, health information capacity, family support, and access to primary care.

Consistent with the SEM, the findings suggest that LS severity was associated with factors across multiple levels, although the strength of associations differed after

adjustment.^{18, 27} In bivariate analyses, greater LS severity was associated with older age, neuropathy risk, polypharmacy, longer diabetes duration, higher HbA_{1c}, and higher BMI. In contrast, lower LS severity was associated with better nutritional status, higher health literacy, stronger family and social support, better PPC, and better access to healthcare services. These bivariate results support the relevance of a multilevel approach because LS severity was related not only to biological and clinical burden, but also to personal and service-related resources. However, the fully adjusted hierarchical regression model showed a more specific pattern: age, neuropathy risk, polypharmacy, and nutritional status remained independently associated with LS severity, whereas health literacy, family and social support, PPC, and access to healthcare services did not reach statistical significance after adjustment for the other variables.

The final hierarchical model explained 32.3% of the variance in LS severity, with an adjusted R^2 of 0.300. This indicates that the 8-SEM-aligned predictors accounted for approximately 30% of the variability in GLFS-25 scores after adjustment. Although this explanatory value is meaningful for a multidimensional geriatric outcome, it also indicates that a substantial proportion of LS severity remains unexplained by the variables included in the model. Other factors, such as physical activity, pain intensity, depressive symptoms, fear of falling, environmental walkability, assistive device use, and rehabilitation history, may also contribute to LS severity but were not included in this analysis. Importantly, the regression findings should be interpreted as adjusted associations rather than evidence of causal or temporal relationships because all variables were measured at one point in time.

At the biological and clinical level, neuropathy risk showed the strongest positive association with LS severity in the final model. Participants who screened positive for neuropathy risk had GLFS-25 scores 6.47 points higher than those without neuropathy risk, after adjustment for other predictors. This magnitude is clinically meaningful because the GLFS-25 captures pain, walking difficulty, daily activity limitation, social function, and mobility-related concerns. Peripheral neuropathy may be associated with impaired protective sensation, reduced proprioceptive feedback, gait instability, and fear of falling, all of which may contribute to mobility-related limitation.^{12, 13} For primary care practice, this finding reinforces the value of routine diabetic foot screening, monofilament examination, fall-risk assessment, and early mobility review among older adults with T2DM. Nevertheless, the cross-sectional design does not establish whether neuropathy risk preceded higher LS severity or whether reduced mobility and poorer health status increased the likelihood of neuropathy-related problems being detected.

Older age was also independently associated with greater LS severity. Each additional year of age was associated with a 0.41-point higher GLFS-25 score after adjustment. Although the coefficient appears modest at the individual-year level, the accumulated difference across a decade of aging may be practically relevant. Aging is accompanied by changes in muscle strength, joint function, balance, endurance, and recovery capacity, and these changes may be amplified by T2DM and comorbid conditions.^{1, 2} This finding is consistent with the clinical understanding that mobility decline in later life reflects both biological aging and disease-related vulnerability. However, age should not be viewed as a nonmodifiable explanation that limits intervention. Rather, it may help identify older adults who require closer monitoring, earlier functional screening, and more proactive supportive care.

Polypharmacy was another significant clinical factor. Each additional medication was associated with a 0.66-point higher GLFS-25 score after adjustment. Polypharmacy may

reflect greater disease complexity, multimorbidity, symptom burden, or exposure to medication-related adverse effects, including dizziness, weakness, orthostatic symptoms, or musculoskeletal discomfort.^{6, 7} In this study, the mean number of current medications was 6.8, suggesting a substantial medication burden. The association between polypharmacy and LS severity should therefore be interpreted as a marker of clinical complexity rather than as proof that medication number directly worsens mobility. For primary care nurses and teams, this finding supports the importance of medication review, monitoring for adverse drug events, and collaborative deprescribing discussions when appropriate.

Nutritional status was the only modifiable intrapersonal factor that remained independently associated with LS severity in the fully adjusted model. Each 1-point increase in MNA-SF score was associated with a 1.41-point lower GLFS-25 score. This finding is biologically coherent because nutritional status is closely related to muscle function, energy balance, physical resilience, and recovery from illness. T2DM and sarcopenia may be linked through insulin resistance, inflammation, reduced muscle protein synthesis, and declining muscle quality.^{2, 4, 5} Poorer nutritional status may coexist with fatigue, weakness, reduced activity tolerance, and lower participation in daily activities, which correspond to several domains of the GLFS-25.^{30, 31} This result supports the practical relevance of brief nutritional screening in community-based diabetes care. However, reverse causality remains possible. Older adults with greater LS severity may have more difficulty shopping, cooking, attending community activities, or maintaining adequate dietary intake; therefore, poorer nutrition may be both associated with and potentially shaped by mobility limitation.

Health literacy was significantly associated with LS severity in the bivariate analysis but was not independently significant in the fully adjusted model. Its coefficient remained in the expected negative direction, suggesting that higher health literacy tended to be associated with lower LS severity, but this association may overlap with nutritional status, clinical burden, or access-related factors. Diabetes self-management requires older adults to understand medication instructions, monitor symptoms, follow dietary guidance, communicate concerns, and seek timely care.^{6, 7} This may be especially relevant in a sample where most participants had low educational attainment.¹⁶ The nonsignificant adjusted association should not be interpreted as evidence that health literacy is unimportant. Rather, health literacy may operate indirectly through nutrition, treatment adherence, symptom monitoring, service use, or communication with healthcare providers. Future studies using mediation or longitudinal path models may clarify whether health literacy contributes to LS severity through these intermediate pathways.

Family and social support and PPC were also significantly correlated with LS severity in bivariate analysis but did not remain independently significant in the fully adjusted model. These findings should be interpreted carefully. Social support and communication may share variance with health literacy, access to care, or nutritional status. They may also have indirect roles that are not fully captured by multiple linear regression. For example, family support may help older adults attend appointments, prepare meals, remember medications, and maintain physical activity. PPC may improve understanding of foot care, safe movement, symptom monitoring, and treatment plans. However, when clinical burden and nutritional status were considered simultaneously, their unique statistical contribution was reduced. This pattern does not contradict the SEM; rather, it suggests that interpersonal and communication factors may work through connected pathways rather than acting as isolated independent predictors.

Access to healthcare services was negatively correlated with LS severity in bivariate analysis but was not independently significant in the final model. Access in this study included acceptability, availability, accommodation, and geographical accessibility.³⁷ In practical terms, access may influence clinic attendance, medication continuity, foot screening, diabetes follow-up, and referral for rehabilitation or nutrition support.^{6,7} Environmental disruptions such as floods, extreme heat, and transportation barriers may further affect continuity of care among older adults with chronic disease.¹⁹⁻²² The nonsignificant adjusted coefficient may indicate that the effect of access overlaps with clinical and intrapersonal factors, or that access influences LS severity indirectly through earlier detection, better self-management, or more timely care. Therefore, access should remain a relevant consideration for primary care planning even if it was not an independent predictor in the final regression model.

Reverse causality is an important interpretive issue. Although better nutritional status, higher health literacy, stronger support, better communication, and greater access may be related to lower LS severity, older adults with less severe LS may also be more able to travel to clinics, communicate with providers, participate in social activities, obtain health information, and maintain adequate nutrition. Therefore, the temporal direction of these relationships cannot be determined. This is particularly important for variables such as health literacy and access, which may be both resources for maintaining function and consequences of better mobility. Longitudinal studies are needed to determine whether these factors precede changes in LS severity over time.

Overall, the findings suggest that LS severity among older adults with T2DM reflects the intersection of biological aging, diabetes-related complications, medication burden, nutritional status, and primary care context. The strongest adjusted associations were observed for neuropathy risk, nutritional status, age, and polypharmacy, while health literacy, social support, PPC, and healthcare access showed theoretically meaningful but nonsignificant adjusted associations. These results support a balanced interpretation: clinical and nutritional factors may be more directly associated with current LS severity, whereas interpersonal and healthcare-access factors may contribute through indirect or context-dependent pathways. For nursing practice in primary care, this pattern highlights the importance of integrating foot screening, medication review, nutritional assessment, health communication, family engagement, and access-sensitive follow-up into routine diabetes care.

Limitations

Several limitations should be considered when interpreting these findings. First, the cross-sectional design prevents determination of temporal sequence or causality. Reverse causality is possible; older adults with less severe LS may have been more able to access health services, maintain nutrition, and obtain health information, rather than these factors necessarily preceding lower LS severity. Second, participants were recruited from PCUs in a single province, and only those who attended or could be reached through primary care services were included, which may introduce selection bias and limit generalizability to older adults in other Thai regions or those with poorer service access. Third, several variables relied on self-report, which may be affected by recall error, social desirability, and common-method bias because multiple predictors were measured from the same respondent at the same time. Fourth, the relatively small proportion of male participants may limit interpretation for older men with T2DM. Fifth, residual confounding from unmeasured factors, such as physical activity, pain severity, depression,

environmental barriers, or socioeconomic conditions, may remain. Finally, although the Thai GLFS-25 is validated, functional limitation was measured by self-report rather than objective performance tests.

Implications for Nursing in Primary Care

For primary care nurses, the findings support a cautious, prevention-oriented mobility approach integrated into routine diabetes care. Because this study used a cross-sectional design, health literacy, nutritional status, neuropathy risk, and access to healthcare should be viewed as clinically relevant factors associated with LS severity, not as confirmed causal targets. Brief LS screening, such as the GLFS-25 or a short prescreen, may help identify older adults with current mobility-related functional difficulty and guide early nursing assessment.^{8, 11} Older adults with positive monofilament findings warrant closer follow-up because neuropathy risk was associated with greater LS severity.^{12, 13} Health literacy should be addressed as a modifiable care focus through clear language, teach-back, and repeated messages on safe movement, foot care, and medication routines.^{16, 17} Nutritional screening with feasible tools such as the MNA-SF may also support early identification of older adults who require dietary counseling or referral, given the links among nutrition, muscle function, and sarcopenia-related pathways in T2DM.^{2, 4, 5} Finally, nurses should assess and address access barriers to sustain continuity of care, especially during service disruptions such as floods or extreme heat.²⁴

Future research should test these nursing implications using longitudinal cohort studies to clarify temporal relationships between health literacy, nutrition, access to healthcare, and LS severity. Nurse-led health literacy and nutritional interventions should also be evaluated through randomized controlled trials or pragmatic primary care trials. In addition, longitudinal path analysis or structural equation modeling could examine whether PPC, access to healthcare, and health literacy mediate changes in LS severity over time.

Conclusions

This study found that LS severity among community-dwelling older adults with T2DM was associated with a combination of biological, clinical, personal, and healthcare-access factors. In the final model, higher health literacy, better nutritional status, and better access to healthcare services were independently associated with lower LS severity scores, whereas older age and peripheral neuropathy risk were associated with greater LS severity. Framed within the SEM, these findings suggest that LS severity in older adults with T2DM should be considered not only in relation to metabolic and neuropathic burden, but also in relation to health information capacity, nutritional status, and access to supportive primary care services. These findings highlight potentially relevant areas for comprehensive nursing assessment and supportive primary care; however, causal and temporal relationships cannot be established from the cross-sectional data.

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