Modified Squat Test for Predicting Knee Muscle Strength in Older Adults

Running Title: Knee Strength Prediction using Squat Test

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ABSTRACT

Background: Methods for evaluating the strength of the knee extensor muscles play a vital role in determining the functionality of the lower limbs and monitoring any alterations that occur over time in older individuals. This study assessed the validity of the modified squat test (MST) in predicting knee extensor muscle strength in older adults.

Methods: This study included a total of 110 older adults. We collected demographic information such as sex, age, body weight, height, and thigh circumference. Muscle strength was assessed by measuring the maximum voluntary isometric contraction (MVIC) of the knee extensors, and by performing the MST (5 and 10 repetitions) and single-leg standing balance test. Stepwise multiple linear regression analysis was used to investigate multiple factors impacting the prediction of knee extensor strength.

Results: Factors such as age, sex, thigh circumference, performance on the single-leg standing eye-open (SSEO) task, and the time required to complete the 10 MST repetitions together explained 77.8% of the variation in knee extensor muscle strength among older adults. We further developed a predictive equation to calculate strength as follows: strength = 36.78 – 0.24 (age) + 6.16 (sex) + 0.19 (Thigh circumference) + 0.05 (SSEO) – 0.54 (Time required to complete 10 MST repetitions) ± 5.51 kg.

Conclusion: The 10-repetition MST is an invaluable instrument for establishing an equation to accurately predict lower limb muscle strength.

Key Words: Modified squat test, Aging, Older adults, Predictive equation, Lower limb, Functional test
1. INTRODUCTION

Knee extensor muscle strength is crucial for older adults because it significantly affects various aspects of physical well-being, mobility, and overall quality of life (1-3). Studies on the relationship between knee extensor strength and health in older adults have consistently demonstrated the importance of maintaining or improving knee extensor strength as individuals age. Decreased knee extensor muscle strength is frequently linked to restrictions in activities of daily living (ADLs) in older adults (4, 5). Adequate knee extensor strength is indispensable for ADLs such as standing up from a seat, ascending stairs, and walking, all of which are pivotal for maintaining function (2, 6, 7). Decreased knee extensor strength is associated with an increased risk of falls in older adults. Falls can have severe consequences, including fractures and a decline in overall well-being (8). Therefore, maintaining knee extensor strength can mitigate these risks.

Assessing knee extensor muscle strength is vital for evaluating lower limb function and monitoring changes over time. This is particularly important in clinical and research settings (9). Several methods have been developed to measure the knee extensor strength. Isokinetic dynamometry is considered the gold standard (10) because it provides a controlled environment and allows for constant angular velocity throughout the range of motion (11). Researchers and clinicians have applied isokinetic testing to measure the peak torque, work, and power of the knee extensors (12). Handheld dynamometers are also commonly used in clinical settings to assess muscle strength, including that of the knee extensors. These portable and cost-effective devices are particularly useful for assessing muscle strength in older adults and individuals with mobility impairments (13). Manual muscle testing (MMT) is another method used to assess knee extensor strength, in which a trained examiner assesses strength using a predetermined scale (14). Although the MMT is less objective than dynamometry, it is frequently used in clinical assessments to identify muscle weakness or imbalances (15). Functional tests such as the sit-to-stand (STS) test or timed up-and-go
test (TUGT) indirectly evaluate knee extensor strength by assessing an individual's ability to perform daily tasks (16, 17). These tests are often used to assess functional limitations and predict fall risks, particularly in older adults (18).

The STS test is a widely used tool for evaluating lower limb strength and mobility in older adults and other populations (18-20). However, like any assessment method, the STS test has limitations, which have been discussed in the literature. The lack of standardized protocols across different studies and clinical settings, which results in variations in chair height, arm position, or number of repetitions, is one of the primary limitations of the STS test (21, 22). Inconsistent results across studies can be a consequence of these discrepancies. The STS test may also be difficult to perform for individuals with severe mobility limitations, resulting in a ceiling effect. This feature makes the test unsuitable for assessing a wide range of functional abilities. Therefore, standardizing testing protocols and considering cognitive and psychological factors can improve the reliability and validity of functional tests in older adults.

The modified squat test (MST) is a functional assessment tool commonly used to evaluate lower-limb strength, mobility, and cardiopulmonary fitness in older adults (23, 24). It is similar to the STS test, and is relatively simple and easy to administer. Thus, it is a practical and efficient assessment tool that can be easily incorporated into clinical or research settings. Compared with the STS test, the MST involves a shallower squatting motion, which can be safer for individuals with limited mobility or for those who are at a higher risk of falling. This modification helps to reduce the risk of injury during testing. Additionally, the MST can be adjusted to accommodate an individual's capabilities by changing the height of the chair or the number of repetitions. This adaptability allows its use across a wide range of functional levels. Hence, the main objectives of the present study were twofold. First, we determined the predictive validity of the MST as an indicator of knee extensor muscle strength in older adults. Second, we identified factors to predict
knee extensor muscle strength in older adults, and developed an equation for strength estimation in this population.

2. MATERIALS AND METHODS

2.1 Participants

This cross-sectional analytical study used a correlational design to create predictive equations. A total of 110 older adults were recruited through outreach efforts in collaboration with community leaders and healthcare volunteers. We included individuals aged ≥60 years (average age of 67.79 ± 6.26 years) who resided in the Muang District of Phayao Province, Thailand. Ethical approval was obtained from the Human Research Ethics Committee of the University of Phayao (approval no. UP-HEC 2/074/61). The bivariate normal model in the G*Power program was used to determine the appropriate sample size. Based on a low correlation (r) value of 0.30, with an alpha value of 0.05 and a power of 0.90, a minimum of 88 volunteers was required for this study to achieve statistical significance. The inclusion criteria were healthy older adult men and women, as well as individuals with manageable symptoms of chronic illnesses such as diabetes and hypertension. The details of the participants who were able to walk independently without the use of walking aids are listed in Table 1. The exclusion criteria were musculoskeletal issues in the lower extremities (e.g., osteoarthritis or rheumatoid arthritis); bone fractures or dislocations and underlying causes; surgical history; neurological disorders affecting balance and muscle strength (e.g., stroke, spinal cord diseases, or Parkinson's disease); and communication, vision, or hearing impairments.

2.2 Research protocol

The participants were provided a comprehensive explanation of the study objectives and data collection procedures. Before commencing participation, the volunteers were required to
provide informed consent by signing a consent form. Demographic data and anthropometric characteristics including sex, age, body weight, height, and thigh circumference were collected from each participant. Before the official commencement of the trial, the participants were allotted 5 min to practice the prescribed movements and ensure their comfort and familiarity with these. The assessment included measurement of the maximum voluntary isometric contraction (MVIC) of the knee extensor muscle, followed by five and ten repetitions each of MST, and a single-leg standing balance test. A minimum of 5 min of rest was provided between each assessment to ensure optimal performance and recovery. The following sequences and methods were applied for the variable measurements:

2.2.1. MVIC of the knee extensor muscle

We evaluated the MVIC of the knee extensor muscle with the participants seated on an N-K table with their knees flexed at 60° (25). To accommodate individual leg lengths, the N-K table was adjusted accordingly. Safety measures were implemented by using a secure belt to stabilize the trunk and upper legs. For the assessment, a push-pull dynamometer (Baseline® Analog Hydraulic Push-Pull Dynamometer, United States) was affixed to the N-K table leg, employing a strap oriented perpendicular to the vertical axis and situated 1 cm above the lateral malleolus (26), as depicted in Figure 1. The participants were provided precise instructions to extend their knees to the fullest extent possible against the push-pull dynamometer while maintaining contraction for 4 s. This testing protocol entailed three rounds of assessment, with a 2-min rest period between each round to ensure participants' readiness and consistent performance. We recorded the maximum force (in kg) exerted during these trials.
2.2.2 Modified squat test

All participants were provided with explicit instructions to assume a prescribed stance, with both feet firmly planted on the floor and spaced shoulder-width apart, and with the hands on the chest (27). The researchers emphasized maintaining an upright posture with the back and knees in straight form. Subsequently, the participants were directed to flex their knees to 60° (28), which was accurately measured using a universal goniometer. Subsequently, the researcher adjusted the chair height to ensure contact between the participant’s buttocks and the chair seat. The core of the assessment revolved around the participants' ability to perform squats using both feet simultaneously, with the primary objective of touching their buttocks to a cushioned seat (27). This squatting and standing sequence was executed in sets of five and ten repetitions, respectively, with the participants striving to complete each repetition with agility and safety (Figure 2). To ensure a comprehensive evaluation, the test consisted of three distinct trials, each separated by a 2-min rest interval to allow the participants to recuperate. We recorded the time required by the participants to successfully complete both five and ten repetitions.

2.2.3 Single-leg standing balance test

The single-leg standing balance test commenced with the participants in standing position, with both feet on the ground and their gaze directed straight ahead. Subsequently, the researcher instructed the participants to transfer their weight onto their dominant leg while crossing their arms over their chests. The non-dominant knee was flexed to 90° and a timer was activated to record how long the participants could maintain their balance (29). The test was conducted three times with a 2-minute break between each trial. In this study, we administered two variations of the single-leg standing balance test: one with the eyes open (SSEO) and the other with the eyes closed (SSEC).
Statistical analyses

We collected the participants' demographic information and used descriptive statistics to express the means and standard deviations. The Shapiro–Wilk test was used to assess the distributions of the variables. We used Pearson's product-moment correlation coefficient statistics to investigate the relationships among the following factors: the MVIC of the knee extensor muscle, subjects' demographic data (sex, age, weight, height, body mass index [BMI], and thigh circumference), and the time taken to complete both five and ten repetitions of the MST. To delve further into the predictive aspects, we performed stepwise multiple linear regression analysis to construct a predictive equation for knee extensor strength that incorporated demographic data and the time required to complete the MST. The model selection criteria included the highest adjusted $R^2$ value while minimizing variance inflation. We included independent variable coefficients in each prediction model based on their significance within the model. All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA) with the significance threshold set at $p < 0.05$.

3. RESULTS

This study included 110 older adults (52 men and 58 women, average age 67.79 ± 6.26 years). The participants' mean weight, height, and BMI were 57.30 ± 8.12 kg, 157.33 ± 8.42 cm, and 23.18 ± 3.12 kg/m², respectively. The average thigh circumference was 47.25 ± 4.21 cm. The average strength of the knee extensor muscles, as measured by MVIC, was 27.50 ± 7.60 kg. The participants required an average of 6.13 ± 2.37 s and 11.88 ± 4.65 s to complete five and ten repetitions of the MST, respectively. The average duration of the single-leg standing balance test were 30.88 ± 31.02 s for SSEO and 4.54 ± 3.01 s for SSEC (Table 1).
Knee extensor muscle strength was associated with various demographic characteristics of the participants, including sex, age, weight, height, and thigh circumference. These associations exhibited varying degrees of correlation, ranging from low to moderate ($r = 0.299–0.670$, $p < 0.005$). We also observed significant negative correlations between knee extensor muscle strength and the time required to complete the two different MST repetitions. Specifically, we observed a moderate negative correlation with the time taken for five repetitions ($r = -0.492$, $p < 0.001$) and a strong negative correlation with the time taken for ten repetitions ($r = -0.722$, $p < 0.001$). Furthermore, knee extensor muscle strength was moderately positively correlated with SSEO ($r = 0.550$, $p < 0.001$) and SSEC ($r = 0.419$, $p < 0.005$). The detailed correlation findings are presented in Table 2 and Figure 3.

Based on the results of the comprehensive multiple regression analysis of the strength of the knee extensor muscles, five factor models were identified (Table 3). In Model 1, the only significant factor affecting knee extensor muscle strength was the time required to complete 10 repetitions of the MST. Conversely, the contributing factors in Models 2–5 included sex, SSEO, age, and thigh circumference. Among the five models, Model 5 exhibited the strongest correlation ($r = 0.888$, $p < 0.05$) and the highest coefficient of determination ($R^2 = 0.778$). This indicates that the combined influence of the time taken to complete 10 repetitions of the MST, sex, SSEO, age, and thigh circumference accounted for 77.8% of the variation in knee extensor muscle strength. The standard error of the estimate was approximately 3.58 kg. Subsequently, we formulated an equation
to predict knee extensor muscle strength with a high degree of accuracy, which is as follows:

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\text{Strength (kg)} = 36.78 - 0.24 \times \text{(age)} + 6.16 \times \text{(sex)} + 0.19 \times \text{(thigh circumference)} + 0.05 \times \text{(SSEO)} - 0.54 \times \text{(time to complete 10 repetitions of the MST)} 
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where ‘sex’ is a binary variable (male = 1, female = 0). This equation is a robust tool for accurately predicting knee extensor muscle strength.

4. DISCUSSION

Knee muscle strength is important for independence and quality of life in older adults (30). Thus, geriatric healthcare should include strategies to assess and improve knee muscle strength. This study aimed to identify a functional test for predicting knee muscle strength in the older adult population. Our results revealed an association between participant characteristics and knee muscle strength. Men generally have stronger knee muscles than women, which can be influenced by hormones, activity levels, and aging (31-33). Although both men and women experience a decline in knee muscle strength with age, women may experience a more pronounced decline after menopause (34, 35). Regular resistance training can help reduce sex differences in muscle strength (36, 37).

Weak knee muscles in women can affect daily activities and the overall quality of life (38). Anthropometric data such as body measurements can predict knee muscle mass in older adults (39). Reduced muscle mass, which is often associated with aging, contributes to decreased knee muscle strength (40). Anthropometric measurements can identify individuals at risk for muscle weakness and mobility problems (16, 41). In the present study, we observed a moderate association between decreased knee muscle strength and thigh circumference. Therefore, the regular assessment of
demographic and anthropometric profiles is important to prevent a decline in muscle strength and reduce fall risk.

The relationship between the MST and knee extensor muscle strength in older adults is important for studying physical function and mobility. We observed a moderate-to-strong association between knee extensor strength and the time taken to complete both five and ten repetitions of the MST. MST reflects knee extensor strength because it involves movements that rely on the strength of these muscles (42). During the test, individuals squat and stand from a seated position, which requires knee joint extension. The knee extensor muscles straighten the knee and lift body weight against gravity (43). The relationship between MST and knee extensor strength lies in the biomechanics of squatting and standing. When moving from a seated to a standing position or lowering into a squat, the knee joint moves from a flexed to an extended position. This requires the quadriceps muscles to contract and straighten the knee joint (44). The knee extensor muscles must generate the necessary force to support and lift the body during the descent into a squat and ascent to a standing position, respectively. Adequate muscle strength is necessary to control these descent and ascent phases and ensure stability of the knee joint (45). The ability to perform the MST effectively indicates sufficient knee extensor muscle strength, whereas weaker knee extensor muscles may lead to difficulties and reduced stability. Thus, the MST can be used to assess the strength and functionality of the knee extensor muscles for daily tasks and mobility.

In this study, the stronger correlation between MST and knee extensor strength for ten repetitions than for five repetitions can be attributed to several factors. Muscle fatigue can accumulate with increasing MST repetitions (46). This accumulated fatigue affects individuals differently depending on their knee extensor strength. Individuals with stronger knee extensors may experience less fatigue (47) and maintain a better form throughout the 10 repetitions, resulting in a stronger correlation with overall muscle strength. Stronger knee extensors have a higher threshold
for engagement, allowing them to sustain a greater force output for longer periods before experiencing significant fatigue (48). This enables individuals with greater knee extensor strength to perform additional repetitions before muscle failure or exhaustion occur. The five repetitions of the MST, which involve rising from a seated position five times consecutively, may be relatively easier for some individuals, especially those with moderate to high knee extensor strength. Therefore, the test may not fully challenge their strength and they may complete it with relative ease, unlike the five-time STS. Thus, five repetitions of the MST may not effectively differentiate between individuals with varying levels of knee extensor strength, leading to a potential ceiling effect. Therefore, an increased number of repetitions allows better differentiation between individuals with varying levels of strength, making it more sensitive for identifying differences in muscle strength. Additionally, maintaining balance during the MST is crucial for preventing falls and loss of stability. Knee extensor strength plays a role in balance by controlling movement and preventing the knee from buckling or collapsing during squatting (49). This explanation is consistent with the outcomes of our study, which demonstrated a moderate association between knee extensor strength and performance in the single-leg standing test.

The combined model indicated that multiple factors significantly influenced knee extensor muscle strength. We analyzed various factors, including the time taken to complete 10 repetitions of the MST, sex, whether the single-leg standing balance test was performed as SSEO, age, and thigh circumference. These factors were selected because they could potentially contribute to knee extensor muscle strength. These factors collectively explained 77.8% of the observed variation in knee extensor muscle strength. This high percentage suggests that the model effectively captured and explained a significant portion of the variance in knee extensor muscle strength. The time required to complete 10 repetitions of the MST was a crucial factor in the model. Individuals who can quickly perform squatting and rising tasks tend to have stronger knee extensor muscles. Sex was
also a significant factor, indicating sex-related differences in knee extensor muscle strength. This aligns with previous research reporting sex disparities in muscle strength, with men typically exhibiting greater strength than women (50). The inclusion of SSEO as a factor suggests that balance, as assessed using the single-leg standing test, plays a role in knee extensor muscle strength. Age of the participant was also considered, highlighting the well-established association between aging and declining muscle strength (50). Thigh circumference was another important factor, indicating that the muscle size and mass in the thigh region directly affect knee extensor strength (51). This is consistent with the understanding that greater muscle mass generally contributes to increased muscle strength. Furthermore, during the multiple regression analysis, when investigating the reverse relationship with the MST as the dependent variable and muscle strength as the independent variable, muscle strength, in conjunction with age as a covariate, impacted physical function performance in older adults by approximately 56%. This finding suggests a bidirectional influence between these variables, further implying that the MST can serve as an indicator of muscle strength.

The substantial variations explained by this model have both clinical and practical implications, suggesting that healthcare professionals and practitioners should consider these factors when assessing knee extensor muscle strength in clinical settings. Strategies to improve knee extensor strength may include targeted exercises to enhance muscle endurance, balance training, and strength-building interventions that can be tailored to sex, age, and individual characteristics. We also present a predictive equation for knee extensor strength, which is a valuable outcome of this study. The equation is as follows: knee extensor strength (kg) = 36.78 – 0.24 (Age) + 6.16 (sex) + 0.19 (thigh circumference) + 0.05 (SSEO) + 0.54 (time required to complete 10 MST repetitions). This equation allows the estimation of an individual's knee extensor strength based on certain
variables. The equation also includes an associated margin of error (± 5.51 kg) to account for variability in the prediction.

Although our study provides valuable insights, it has several limitations. First, the measurement of knee extensor muscle strength using a push-pull dynamometer may not be the most accurate method, unlike the isokinetic dynamometer, which is considered the gold standard. Although the push-pull dynamometer is widely used because of its accessibility and accuracy in assessing the maximum force produced by isometric muscle contraction, future research should investigate the relationship between MST performance and knee muscle strength measured using the gold standard isokinetic dynamometer. Another limitation of our study is the lack of a separate analysis of women and men. However, this limitation was mitigated by the relatively equal proportions of women and men in our sample. Although we included sex as a cofactor in predicting knee extensor muscle strength, future studies should conduct separate analyses to derive sex-specific prediction equations for a more comprehensive analysis.

The results of this study emphasize the multifactorial nature of knee extensor muscle strength and highlight the combined influence of various factors, including MST performance, sex, balance, age, and thigh circumference, in explaining a significant proportion of the variation in knee extensor strength. These findings underscore the importance of comprehensive assessments and tailored interventions to address and optimize knee extensor muscle strength for different populations, particularly in the context of aging and functional capacity.

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**Informed Consent Statement:** Informed consent was obtained from all participants involved in the study.

**Conflicts of Interest:** The authors declare no conflicts of interest.