Hong Kong Physiotherapy Journal
Vol. 44, No. 1 (2024) 1–10
DOI: 10.1142/S1013702523500099

Hong Kong Physiotherapy Journal
https://www.worldscientific.com/worldscinet/hkpj

Lower extremity muscle strength equation of older adults assessed by Five Time Sit to Stand Test (FTSST)

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Received 5 December 2022; Accepted 16 February 2023; Published 12 April 2023

Background: The decline in lower limb muscle strength, one of the risk factors for falling in the older adults, puts older persons at an increased risk of falling. The assessment of the lower limb muscle strength is very important.
Objective: The purpose of this study was to construct the equation for predicting knee extensor muscle strength based on demographic data and the results of the Five-Time Sit-to-Stand Test (FTSST).
Methods: A total of 121 healthy elders (mean age 68.00 ± 7.26) were asked to complete the FTSST and submit the demographic information. By using a stationary push–pull dynamometer, the knee extensor strength of each participant was assessed. The multiple regression analysis was used to explore knee extensor strength prediction equation.
Results: The findings demonstrated that the knee extensor strength equation was developed using variables obtained from gender, weight, and time to complete the FTSST. The equation was found to have a high correlation ($r = 0.838$) and 70.1% estimation power. Its formula was as follows: Knee extensor strength $=$ $32.735 + 3.688$ (gender; female $= 0$ or male $= 1$) $+ 0.189$ (weight) $- 2.617$ (time to complete the FTSST). However, there was an estimating error in this equation of 4.72 kg.
Conclusion: The determining factors influencing knee extensor strength, which can be utilized to estimate the strength in elderly individuals, are demographic variables including gender, weight, and the time taken to complete the FTSST.

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Keywords: Isometric dynamometer; older adults; demographic data; functional test; prediction.

Introduction

Movement from sitting to standing (Sit-to-stand; STS) is a very necessary activity for people and it is an activity that a person repeats on a daily basis. It can be categorised as a basic bodily movement that is necessary for the start of additional movements in daily life.[1] Falls are a common and serious problem in older adults, and various factors contribute to the risk of falling, including physical impairments such as decreased strength and mobility. Knee extensor strength is a key factor in maintaining physical function, including the ability to perform the sit-to-stand task, which is a measure of lower limb strength and mobility.[2] The older adults are more susceptible to injury and treatment challenges than any other age group, making falls prevalent, and a severe health issue for them.[3] Fractures, brain injuries, and finally death were the most severe injuries caused along by falls.[4] It was discovered that falls among the elderly could account for up to 40% of accidental deaths and that one person died from a fall every 35 min. A decline in lower limb strength was the primary factor in elderly falls.[5–7] As people age, their neuromuscular systems deteriorate, losing strength,[8,9] and adaption techniques to counteract this deterioration, such as altered muscle activation.[10] The skeletal muscle mass starts to decline when it is 50 years old and it has been shown that the lower limbs experience this decline more noticeably than the upper limbs.[11–13] In order to effectively screen for and monitor falls, it is crucial that elderly people have strong leg muscles.

Knee extensor strength, sit-to-stand performance, and falling are interrelated factors that can affect the physical function and mobility of older adults.[14–16] Knee extensor strength is an important indicator of leg muscle strength, which is crucial for activities of daily living, including standing up from a seated position (sit-to-stand).[17,18] Poor knee extensor strength can result in a decreased ability to perform the sit-to-stand task, which can increase the risk of falls.[19] Research has shown that older adults with weaker knee extensor muscles have a decreased ability to perform the sit-to-stand task and are at a higher risk of falls compared to those with stronger knee extensor muscles.[20,21] This association is thought to be due to the role that knee extensor muscles play in supporting the body during weight transfer and maintaining balance during dynamic activities.[22] Therefore, a decrease in knee extensor strength can lead to a decreased ability to perform the sit-to-stand task, which can increase the risk of falls.

Knee extensor strength can be measured in both direct and indirect methods. Direct methods involve measuring the force produced by the knee extensors directly. Examples of direct methods are as follows: Isokinetic dynamometry: This method measures knee extensor strength by having the subject perform concentric and eccentric contractions against a resistance that is constant throughout the range of motion.[23] Maximal voluntary contraction (MVC): This method measures the maximum force that a person can produce during a voluntary isometric contraction of the knee extensors.[24] While dynamometry is widely considered as the gold standard for measuring muscle strength, its widespread application in community-based studies involving a large number of participants may be hindered by several limitations. The most substantial limitations of dynamometry include its cost, size, and requirement for a designated testing space, as well as the need for an operator with specialized knowledge and expertise. Indirect methods involve measuring the knee extensor strength indirectly, typically through functional tasks or movements. Examples of indirect methods are as follows: Sit-to-stand test: This test measures the knee extensor strength by having the subject stand up from a seated position and return to a seated position. The time taken to complete the task is used as an indirect measure of knee extensor strength.[18] Stair climbs test: This test involves measuring the time taken to ascend and descend a set of stairs, which is an indirect measure of knee extensor strength as well as other lower limb muscle strengths.[25] The functional test is thus a practical indirect tool for assessing knee extensor strength. The STS test is a functional test that is frequently used to evaluate the physical capabilities, balance, and strength of senior individuals[26–28] since it is a simple, cost-free test that is appropriate for use in community evaluation.

Older adults find it challenging to sit down or rise and doing so raises their risk of falling.[29] STS task involves the coordinated activation of multiple muscle groups, including the knee extensors as well as the hip extensors, ankle plantar flexors, and trunk muscles.[30] It was also a mechanically challenging test of these muscles function for older adults, especially knee extensor muscles. According to Hughes *et al.*, standing up from a chair required older persons to exert 78% of their peak knee extensor contraction force.[28] Jones *et al.* found a high correlation between the number of repetitions for standing up from sitting at 30 s and the maximum force of hamstring contraction in the older adults.[14] According to Corrigan *et al.*, there is a moderate correlation between the length of time spent standing from sitting and lower limb strength.[31] As a straightforward evaluation of knee extensor strength, the STS test has been demonstrated to be useful.

The strength of the muscles in the lower limbs is influenced by additional factors as well. According to research by Takai *et al.*, the Power index of the STS test is based on body weight, leg length, and the amount of time spent up from sitting.[18] The cross-sectional areas of the quadriceps and the elderly's maximum voluntary isometric contraction (MVC) were highly correlated. Additionally, Chen *et al.* discovered a direct correlation between body composition data and leg muscle volume as determined by magnetic resonance imaging (MRI).[32] Height, weight, waist, thigh, and other anthropometric measurements are fundamental physical measurements that may have a significant impact on how strong the muscles are in older people. Numerous publications have utilized the STS test as a means of evaluating the strength of knee extensor muscles in older adults. However, the STS test only provides an assessment of muscle function as a time complete the test and does not yield a numerical representation of actual muscle strength. As a result, the development of an equation to predict knee extensor muscle strength is crucial for both clinical practice and future research. The ability to stand up from a seated position as a test of leg muscle strength prediction equation, however, has not been employed in any studies. Therefore, the purpose of this study was to determine the equation for estimating lower limb muscular strength using the subject's basic physical characteristics and variables related to their ability to stand up from a sitting position. The new findings from this study are based on the aim to develop a predictive equation for knee extensor strength based on the relationship between knee extensor strength and sit-to-stand performance in healthy older adults. The results of this study provide a novel contribution to the existing literature by demonstrating the feasibility of using the sit-to-stand performance as a predictor of knee extensor strength in healthy older adults. The predictive equation developed in this study can be used as a simple and practical tool for assessing knee extensor strength in older adults in clinical and research settings. By establishing a relationship between sit-to-stand performance and knee extensor strength, this study has the potential to contribute to the development of new approaches for improving physical function and reducing the risk of falls in older adults.

Materials and Methods

Participants

This cross-sectional study was conducted among community-dwelling older adults in Phayao Province, Thailand. The number of 121 older adults participants was calculated based on a correlation study of Corrigan *et al.* using the G*Power version 3.1.5.[31] Elderly persons who were 60 years of age or older, in good health, or who had chronic conditions such as diabetes or mild hypertension were able to walk independently without walking device met the inclusion criteria. The exclusion criteria were problems related to the musculoskeletal system of the lower extremities, such as osteoarthritis, rheumatoid arthritis, fracture, or dislocation. The neurological problems that affect balance and muscle strength, such as stroke and spinal cord injury, Parkinson's disease, and who had problems related to communication, vision and hearing were also excluded. Before starting the study, the research protocol (No. 2/030/58) was submitted to and approved by the University of Phayao Ethics Committee in Human Research based on the Declaration of Helsinki's ethical principles.

Research protocol

All participants provided written informed consent after being apprised of the study's protocol. The eligible participants were questioned and their demographic information (such as gender, age, weight, height, leg length, thigh circumference, history of falls, and history of other injuries) was evaluated. The Five-Time Sit-to-Stand Test (FTSST) and a test of knee extensor strength were administered to the subjects over the course of two days separated by 48 h.[33] The participants allocated approximately 20 min for each test session on a daily basis. The subjects were given five minutes to practice the movements before the trial began. After becoming familiar to the movements, the individuals officially carried out the experiment. The variable measurement sequence and the variable measurement method were conducted as follows:

(1) Five-Time Sit to Stand Test (FTSST)
Participants were instructed to perform FTSST by keeping the knee joint bent at 100° on the standard chair, both arms across the chest area.[34] To complete each movement, the researcher instructed participants to begin moving and keeping time while stating "start.". The patients were instructed to stand up and sit down five times as swiftly and safely as they could, completing a total of three rounds with a five-minute break in between. They had to stand up with their hips and knees fully extended before squatting down to sit. When sitting down, they had to sit with their buttock fully touching the chair and the back perpendicular to the floor before the next standing up. The quickest FTSST completion time was recorded. The FTSST performance was measured in second.

(2) The Maximum Voluntary Contractions (MVCs) test
The participants underwent a test to measure the MVCs force of the knee extensor muscles while seated on the NK table with their knees flexed to a 60° angle. Depending on the participants' leg lengths, the NK table's seating could be adjusted. A safety belt was used to stabilize the trunk and upper legs. The push–pull dynamometer (Baseline® Analog Hydraulic Push–Pull Dynamometer, United States) that was mounted to the NK table's leg using a strap perpendicular to the vertical axis was positioned 1 cm above the lateral malleolus (Fig. 1). The participants were instructed to extend their knee as far as they could against the push–pull dynamometer, hold for 4 s, complete three rounds of testing with a 5 min break in between, and record the maximum force. The MVCs tests are quantified in kilograms.

Fig. 1. Maximum Voluntary Contractions (MVCs) test using the push–pull dynamometer that was mounted to the NK table's leg.

Statistical analysis

The participant's demographic information was presented as means and standard deviations using descriptive statistics. The Shapiro–Wilk test was used to test for distribution of all variables. Pearson product moment correlation coefficient statistics were used to determine the relationship between knee extensor strength and subject's demographic data (gender, age, weight, height, leg length) and time to complete FTSST. The Stepwise Multiple Linear Regression Analysis was used to analyse multiple regression and construct a knee extensor strength prediction equation from the variables including subject's demographic data and time to complete FTSST. Models were selected based on the highest adjusted R^2 and lowest degree of variance inflation. Independent variable coefficients included in each prediction model were selected based on significance within the model. All statistical analyses were tested using SPSS version 21 (SPSS Inc., Chicago, IL, USA), the significance level was set at 0.05 for all statistical tests.

Results

A total of 121 elderly participants consisted of 50 males and 71 females, mean age 68.00 ± 7.26 years,

Table 1. Subject demographic data and anthropometric characteristics variables.

Variables ($n = 121$)	Mean ± SD
Gender (males/females)	50/71
Age (years)	68.00 ± 7.26
Weight (kg)	54.33 ± 10.47
Height (cm)	155.56 ± 7.65
Body mass index; BMI (kg/m^2)	22.44 ± 3.92
Leg length (Centimeter)	74.99 ± 4.24
Thigh circumference (Centimeter)	43.25 ± 5.49
Falling in last 6 months (%)	21.49

mean weight 54.33 ± 10.47 kg, mean height 155.56 ± 7.65 cm, mean body mass index (BMI) 22.44 ± 3.92 kg/m^2. The time to completed FTSST averaged 10.79 ± 2.09 s and the average maximum strength of the knee extensor muscles was 16.32 ± 8.54 kg (Table 1).

The demographic information of the participant (gender, age, weight, height, leg length, and thigh circumference) was correlated with knee extensor strength at low to moderate levels ($r = -0.28$–0.51, $p < 0.01$). A strong negative correlation ($r = -0.77$, $p < 0.001$) was found between knee extensor strength and the FTSST completion time variable. The correlation findings are shown in Table 2 and Fig. 2, respectively.

Three prediction models for knee extensor strength emerged from the analysis of multiple regression. Model 1 demonstrated that the strength of the knee extensors was only affected by one component, the time to finish the FTSST (seconds), which was significant ($r = 0.773$, $p < 0.05$), with the R^2 for the equation showing that approximately 59.7%. The estimated standard error of measurement is 5.44 kg. Model 2 identified body weight (kg) and time to finish FTSST (seconds) as independent predictor variables ($r = 0.812$) with a p-value < 0.05, and the R^2 for the equation indicated that around 65.9%. 5.03 kg is the anticipated standard error of estimation for this model. For a significant prediction model of knee extensor strength ($p < 0.05$), Model 3 incorporated time to complete FTSST (seconds), body weight (kg), and gender ($r = 0.838$). The R^2 for the equation indicated that roughly 70.1%. The estimated standard error of measurement is 4.72 kg.

As a result, the equation for knee extensor strength's predictive accuracy was $32.735 + 3.688\ (\mathrm{G}) + 0.189\ (\mathrm{BW}) - 2.617\ (t\text{-FTSST}) + 4.72$ (kg),

Table 2. Correlation between demographic information of the participant, time to completed FTSST variable and knee extensor strength variable.

	Knee extensor strength variable
Demographic data Variables	
Gender	0.402** (p-value < 0.001)
Age	−0.277* (p-value $= 0.001$)
Weight	0.514** (p-value < 0.001)
Height	0.472** (p-value < 0.001)
BMI	0.294* (p-value $= 0.001$)
Leg length	0.387** (p-value < 0.001)
Thigh circumference	0.289* (p-value $= 0.001$)
Time to completed FTSST Variable	−0.773** (p-value < 0.001)

Notes: **Correlation is significant at $p < 0.001$, *Correlation is significant at $p < 0.005$.

where G stands for gender (male = 1, female = 0), BW for body weight, and t-FTSST for time to complete FTSST variable. Table 3 and Fig. 3 show the regression analysis findings for the knee extension strength prediction models.

Discussions

According to the findings of this study, the variables from the FTSST can be utilized to predict the strength of the knee extensor muscles along with demographic data variables including gender and body weight. The co-factor of these three variables was revealed to have a strong positive correlation ($r = 0.838$) with knee extensor strength. First, knee extensor strength was influenced by gender. This is in line with a study by Bishop *et al.*, which discovered that males had larger muscles than females due to occupations, sports, and activities that need greater muscle strength than female.[35] Additionally, Leblanc *et al.* reported that gender was the strongest predictor of lower body strength, with correlation coefficients ranging from −0.772 to −0.634.[36] Minematsu *et al.* demonstrated that gender affected physical performance for all types of muscle strength and interactions (gender ∗ muscle strength).[37] As a result, gender

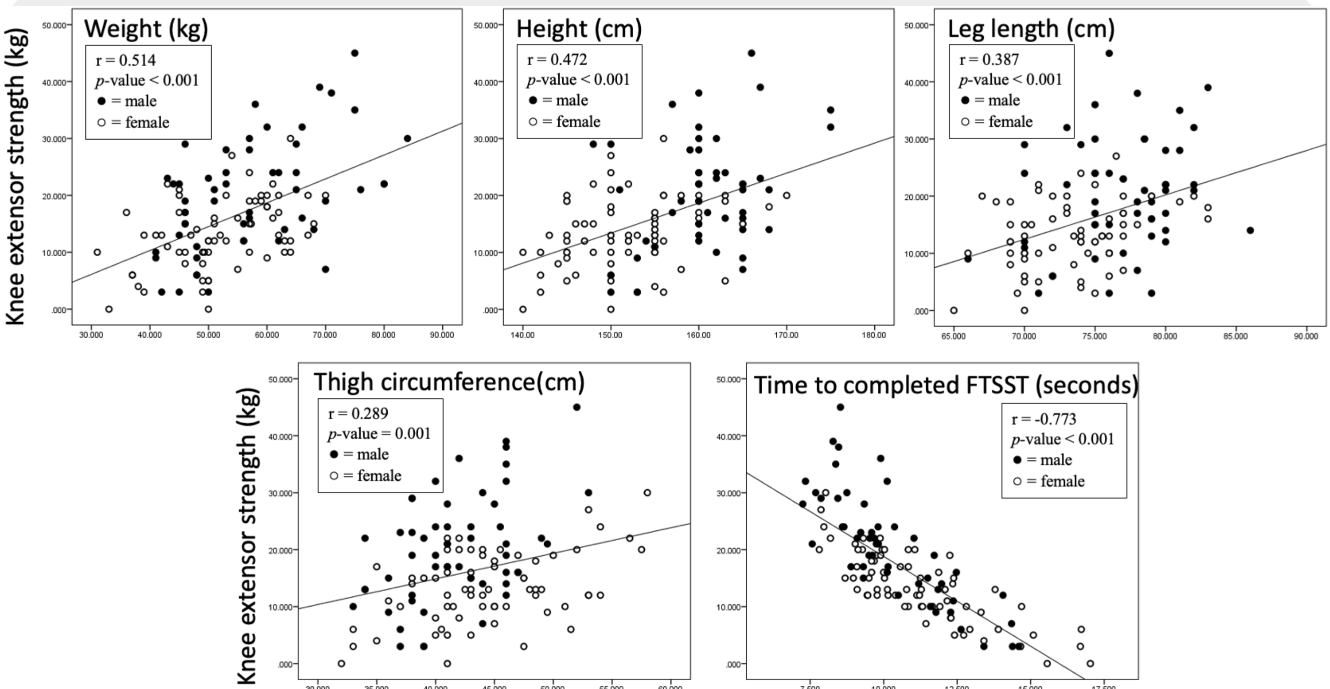

Fig. 2. Scatter plot graph showed relationship between knee extensor strength variable and demographic information of the participant and time to completed FTSST variable.

Table 3. Model of regression analysis for knee extensor strength with different predictive variables.

Model	Included variables	β	p-value	r	Adjusted r^2	SEE
1	Constant	50.320	< 0.001**	0.773	0.597	5.439
	t-FTSST	−3.152	< 0.001**			
2	Constant	34.202	< 0.001**	0.812	0.659	5.027
	t-FTSST	−2.753	< 0.001**			
	Weight	0.218	< 0.001**			
3	Constant	32.735	< 0.001**	0.838	0.701	4.723
	t-FTSST	−2.617	< 0.001**			
	Weight	0.189	< 0.001**			
	Gender	3.688	< 0.001**			

Notes: **Correlation is significant at $p < 0.01$, SEE is standard error of estimation, Gender was coded as a binary variable, with female = 0 and male = 1.

plays a crucial role in predicting knee extensor strength.

Second element that influences the strength of the knee extensor muscles is body weight. According to a study by Slemenda *et al.*, body weight in men was positively correlated with knee extensor muscle strength in a marginally significant manner ($r = 0.222$, $p = 0.005$).[38] Contrarily,

Knee extensor strength (kg) = 32.735 + 3.688(G) + 0.189(BW) - 2.617(t-FTSST)

Fig. 3. Knee extensor strength's predictive equation, G = gender (male = 1, female = 0), BW = body weight, and t-FTSST = time to complete FTSST.

it was found that in females ($r = 0.004$, $p = 0.985$) body weight was not correlated with knee extensor muscle strength.[38] In addition, Miyatake *et al.*'s study demonstrated a statistically significant positive correlation between leg strength to body weight and lean body mass in men at a high level ($r = 0.708$, $p < 0.0001$) and moderately in women ($r = 0.482$, $p < 0.0001$).[39] It was noticed that one of the elements affecting the strength of the lower limb muscles was the measurement of body weight variables that were directly associated to lean body mass. Additionally, it appears that a person's weight directly influences how well they can stand during the test because the subject can swiftly and easily get up from a chair to go upward and forward, one must rely on the force produced by the knee extensor muscle group (the knee extensor moment), which fights gravity's pull on the body weight in the direction of landing. As a reason, if someone is heavier, they must rely more on their knee extensor muscles than someone who is lighter. Because of this, body weight is another common characteristic that may be used to predict how strong the knee extensor muscles will be in tests of standing–sitting capacity.

Third, the study discovered a relationship between predictive muscular strength and the time to completed FTSST variable. The time taken to complete the FTSST serves as an indicator of the strength of the knee extensor muscles, with a shorter completion time suggesting greater strength. A study conducted by Poncumhak *et al.* classified older adults as being at risk of falling or not based on their completion time of the FTSST. Participants who were unable to complete the FTSST within 10.02 s were considered to be at risk of falling, whereas those who completed the test within this time frame were considered to be non-falling risk.[40] Furthermore, it is in line with the research by McCarthy *et al.* that investigated the relation between STS testing and older women's leg muscle strength.[41] The FTSST showed that the ability to stand up from a seated position was a moderate predictor of leg muscular strength ($r = -0.29$ for hip extensors and -0.46 for knee extensors).

It was discovered that multiple recessions' analysis could produce equations for predicting knee extensor strength. Three variables were established that affected knee extensor strength: weight, gender, and time spent performing the five-sitting-stand-up test. These variables had a prediction power of "equivalent to 78.2%". The prediction for the strength of the knee extensor muscle was off by 4.37 kg, which was an acceptable value. The findings of this study will benefit a leg muscle strength test known as the FTSST, which can measure the strength of the knee extensor in numerical units of the force that the muscle can truly contract. Taking this test is simple and inexpensive. Additionally, it is practical to test for communities that need to test repeatedly. It is a substitute for pricey muscle strengthening tools that are only employed in large educational institutions or medical facilities. The FTSST has been widely recognized for its utility as a predictor of lower body muscle strength. However, its scope extends beyond that as it can also serve as an indicator of several other aspects of physical fitness. These include lower body muscle endurance, balance and coordination, cardiovascular fitness, physical function, and frailty, making it a valuable tool for assessing overall physical health and well-being in older adults.[42] This study still has several limitations, however. The sample size was modest. Therefore, larger samples should be employed in future research to ensure that the findings are a more accurate reflection of the elderly population. The measurement of extensor muscle strength using a push–pull dynamometer is not considered as the gold standard method, which is the isokinetic dynamometer. The maximum form of force obtained from the push–pull dynamometer is through the force produced by the muscle's isometric contraction. However, despite this, the push–pull dynamometer is widely used for measuring muscle force due to its accessibility and accuracy. Therefore, future studies should consider examining the relationship between STS performance and machine-measured extensor muscle strength using the gold standard isokinetic dynamometer.

Conclusions

This study discovered that knee extensor muscle strength was influenced by gender, weight, and the amount of time spent performing the five time sit to stand test (FTSST). In the form of an equation, it can be used to predict the strength of the knee extensor muscles.

Conflict of Interest

The authors declare no conflict of interest.

Funding/Support

This research project was funded by the Thailand Science Research and Innovation funds and the University of Phayao (Grant No. FF66-UoE009) and School of Allied Health Science (AHS-RD-65003).

Author Contributions

Conception and design of the study was made by W. Tapanya and N. Sangkarit; acquisition of data was made by W. Tapanya, N. Sangkarit and S. Konsanit; analysis and/or interpretation of data were made by W. Tapanya; drafting the paper was made by W. Tapanya; revising the paper critically for important intellectual content was made by W. Tapanya, N. Sangkarit and P. Amput. Statistical analysis was made by W. Tapanya; measuring the outcome measures were made by W. Tapanya, N. Sangkarit and S. Konsanit; they had enough experience in the specialized areas. Funding acquisition was made by W. Tapanya and P. Amput. All authors were involved in the approval of this paper yet to be published.

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