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RESEARCH PAPER

Comparison of toe pressure strength in the standing position and toe grip strength in association with the presence of assistance in standing up: a cross-sectional study in community-dwelling older adults

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Key summary points

Aim The aim of this study was to examine the association between toe pressure strength in the standing position and the presence of assistance during standing up in the older adults.

Findings The results showed that even a strong toe grip strength may not contribute to "no" assistance in standing up. On the other hand, stronger toe pressure strength in the standing position may contribute to "no" assistance in standing up.

Message Toe pressure strength in the standing position may be one of the important functions among those associated with standing up. In addition, this study offers the possibility of contributing to the rehabilitation of older adults who need to improve their ability to stand up without assistance.

Abstract

Purpose We believe that toe pressure strength in the standing position, which is closer to the actual movement, is more associated with standing up in the older adults than the conventional toe grip strength. Therefore, the purpose of this study is to examine the association between toe pressure strength in the standing position and the presence of assistance in standing up in the older adults.

Methods Ninety-five community-dwelling older adults (82 ± 8 years old, 72% female) were included in this study. The patients were evaluated based on their need for assistance in standing up. Physical functions, including toe pressure strength in the standing position, toe grip strength, hand grip strength, knee extension strength, one-leg standing time with eyes open, and maximal walking speed, were measured.

Results When compared with and without assistance to stand up, the group requiring assistance had weaker toe pressure strength in the standing position than the group without assistance ($p = 0.015$, ES = 0.53). After adjusting for confounding factors, the final model revealed that toe pressure strength in the standing position was associated with the use of assistance in standing up (odds ratio 0.94 [0.88–0.99, $p = 0.025$]).

Conclusion Toe pressure strength in the standing position was associated with the use of assistance in standing up in older adults. Improving toe pressure strength in the standing position may facilitate the ability of older adults to stand up.

Keywords Toe pressure strength in the standing position · Toe grip strength · Toe muscle strength · Presence of assistance in standing up · Older adults

Introduction

The ability to stand up is essential for people to move around and perform ADLs independently. A previous study showed that adults perform about 60 standing up movements per day

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in a variety of ADL situations [1]. However, as people get older, their physical functions decline, leading to difficulties in standing up [2]. Older adults have been shown to adopt a more sedentary lifestyle when they have difficulty standing, and this lifestyle change is associated with the risk of sarcopenia and death [3, 4]. Older adults who have difficulty standing up use tools, such as handrails and canes, to stand up [5]. On the other hand, older adults who are able to stand up easily spend less time in a sitting position, perform more physical activities, and have more active lifestyles [6]. These reports suggest that standing up is an essential part of ADLs and that interventions are needed to facilitate standing up to promote health.

Muscle strengths, such as quadriceps, gastrocnemius, and tibialis anterior muscles, are considered to be the most important physical function for the standing up movement [7]. We hypothesize that the strength of the toes, the only part of the body that is in contact with the floor and has mobility, is associated with standing up movement. Toe muscle strength in older adults has been reported to be associated with components of gait (e.g., walking speed and stride length) and falls [8, 9]. Interestingly, the decline in toe muscle strength with aging has also been shown to be greater than hand grip strength and knee extension strength [10]. Thus, toe muscle strength has been shown to be clinically relevant in older adults. To date, toe muscle strength has been assessed by toe grip strength in the sitting position, but we believe there are several problems with this method. The first is the measurement position. The posture for walking and balancing that is associated with toe muscle strength is the standing position. In the standing up movement, the toes must also support the weight of the body as it moves from a sitting position to a standing position. On this basis, we believe that measurement in the standing position, which is closer to the actual movement, better reflects the standing ability of the subject. The second is the mode of locomotion that exerts muscular force. Many studies have evaluated the muscular strength to grip with the toes, however, when actual movements are confirmed, we do not believe the movements to grip with the toes are confirmed. In fact, a vertical force is generated against the ground when standing up [11]. Therefore, it is preferable to evaluate the muscle force that compresses the floor surface vertically rather than the muscle force that grips with the toes. Finally, the presence of pain in a certain number of individuals during evaluations and interventions may be another problem. In particular, older adults with hallux valgus experience pain when they flex their toes deeply, making measurement difficult. Some reports indicate that toe gripping exercises not only do not have a beneficial effect, but also increase the pain [12]. To solve these problems, we devised a method to evaluate muscle strength by applying pressure to the floor surface with the toes in the standing posture.

We measured the toe pressure strength in the standing position and confirmed the reliability of the obtained values [13]. At the same time, we reported the criterion-related validity as an indicator of muscle strength [13]. In addition, toe pressure strength in the standing position discriminated the risk of falling in older adults [14]. Thus, the toe pressure strength in the standing position, which is close to the actual movement, has clinical significance. However, the association between toe pressure strength in the standing position and standing up movements in older adults has not been clarified. Given that vertical forces are generated when standing up [11], it is inferred that toe pressure strength in the standing position, which is measured by vertically pressing on the floor in a standing posture, is another muscle force related to standing up. Moreover, in the standing up movement, the toe pressure strength in the standing position may be more relevant than toe grip strength.

Therefore, this study aimed to examine the association between toe pressure strength in the standing position and the presence of assistance in standing up in older adults. Additionally, the degree of association was compared with toe grip strength in the sitting position. The association between the use or nonuse of assistance in standing up and toe pressure strength in the standing position will contribute to interventions for older adults who have difficulty standing up. Furthermore, we believe that the significance of evaluating toe pressure strength in the standing position can be demonstrated.

Materials and methods

Participants

In this cross-sectional study, older adults who participated in a physical fitness test were included. Participants were recruited by posting flyers, calling for participants by staff members, and posting on the website. Physical fitness test was held at the local communication center and gymnasium. Among the participants, some required long-term care and were undergoing day-care rehabilitation. The certification of participants requiring long-term care is granted by the long-term care insurance system, which was enacted in response to the accelerated aging of Japan's population and the rising level of care required by older adults [15]. The physical fitness test was held in August 2019, July 2022, and August 2022. Since all three sessions were held at different locations, there was no duplication among the participants. The exclusion criteria were participants younger than 64 years, those who required assistance in walking, those who were paralyzed or had fractures, those who could not stand up even with assistance, and those with missing values. The participants in the physical fitness test were fully informed of the content and purpose of the study, and their consent and cooperation were sought after gaining their understanding. We explained that participation in this study was voluntary and informed them that they would not be disadvantaged if they refused to participate. This study was conducted after obtaining approval (22FZX09) from the Ethics Review Committee of Nishikyushu University.

Methods

Basic information of participants, including gender, age, and level of long-term care required, was recorded, and their height, weight, and body mass index were measured. We also evaluated whether the patient required assistance in standing up from a chair in daily life. Physical functions, including toe pressure strength in the standing position, toe grip strength in the sitting position, hand grip strength, knee extension strength, one-leg standing time with eyes open, and maximal walking speed, were measured. In addition, cognitive function was assessed using the Mini-Mental State Examination (MMSE).

Assessment of ability to stand up from a chair

The standing up movement was assessed based on whether the patient needed assistance in standing up from a chair in daily life. A similar assessment was incorporated in the Kihon Checklist, which evaluates frailty and the need for long-term care certification in older adults and is a standardized assessment that is relevant to the daily lives of older adults [16]. In this study, a chair with a seat height of 40–42 cm, which is commonly sold in Japan, was used for the evaluation. The participants were required to stand up from the chair as they normally do in their daily lives. Older adults who could not stand up without pushing the seat with their hands, putting their hands on their knees, or holding onto an object were defined as requiring assistance in standing up.

Toe pressure strength in the standing position

Toe pressure strength in the standing position was measured using a toe pressure measuring device (S-14030, Takei Scientific Instruments Co., Ltd., Niigata, Japan). The limb position was measured in the standing position. The ankle joint was secured with an attached belt, the upper extremities were placed in a drooping position, and the participants were instructed to look forward. The use of handrails or other devices during measurement was prohibited. The measurements were adjusted so that only the toes apical to the first to fourth metatarsophalangeal joints were placed on the force plate and that the measurements did not reflect ankle joint plantar flexion muscle strength. The participants were instructed to not lift their heels and exert pressure on the floor with their toes. The duration of toe pressure on the floor was set at 5 s, and weight shift was allowed when exerting force. Due to the device's characteristics, the measured values do not increase unless a vertical force is applied to the force plate with the toes, only a simple forward shift of the center of gravity. The toe pressure measuring device used in this study was developed by us in collaboration with Takei Scientific Instruments Co., Ltd. In our preliminary study, the developed toe pressure device was found to be highly reliable (right ICC = 0.85, left ICC = 0.78) [13]. The authors also reported a more than moderately significant correlation with hand grip strength, knee extension strength, ankle joint strength, and skeletal muscle mass of the limbs, indicating criterion-related validity as an assessment of muscle strength [13]. Furthermore, toe pressure strength in the standing position, as measured by our toe pressure measuring device, was shown to be clinically useful in logistic regression analysis with various variables entered, showing an association with the risk of falling in older adults [14]. Therefore, measurements were performed three times on each side, and the maximum value of the left and right sides was added to obtain the toe pressure strength in the standing position (Fig. 1).

Other measurements

Toe grip strength was measured using a toe muscle strength meter (T.K.K. 3364, Takei Scientific Instruments Co., Ltd., Niigata, Japan). This measuring instrument is reported to be highly reliable and is used in many studies [17–19]. The limb position was measured in the sitting position. The trunk was placed in a vertical position, and the hip and knee joints were unified at 90° of flexion. To prevent the ankle joint from moving in, the patient was secured with a belt, and the measurement was performed by pulling the bar of the machine with the toes [20]. Measurements were taken twice. The sum of the maximum values on the left and right sides was taken as the toe grip strength.

Hand grip strength was measured using a Smedley-type digital grip strength meter (T.K.K. 5401, Takei Scientific Instruments, Niigata, Japan). Grip strength measurement using the Smedley type is another method that has been reported to be reliable [21]. While standing, the participants were asked to extend the elbow joint, and the proximal interphalangeal joint of the index finger was adjusted to 90°. During the measurements, the examiner ensured that

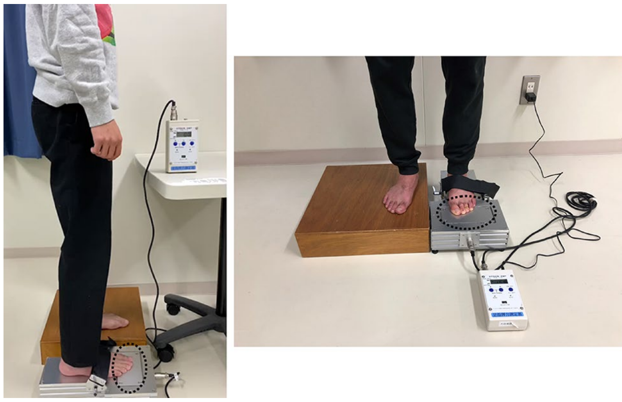

Fig. 1 Measurement of toe pressure strength in standing position. Circles indicate force plates. In the standing position, the force plate should be adjusted so that only the toes ride on the force plate. Ankle joint is fixed with a belt, and force is applied to pressing on the floor with the toes

the upper limbs did not touch the lower limbs or trunk [22]. Measurements were taken twice, alternating between left and right, and the sum of the left and right values was taken as the hand grip strength.

Knee extension strength was measured using a handheld dynamometer (μTasF-1, Anima Co., Ltd., Tokyo, Japan). The limb position was measured in the sitting position. Knee extensor strength using a hand-held dynamometer has been reported to be reliable and shown to be clinically useful [23, 24]. The trunk was placed in a vertical position, and both upper limbs were crossed on the chest. A portion of the sensor was fixed to the distal lower leg with an attached belt. Measurements were taken twice on each side, and the sum of the maximum values on each side was used as the knee extension strength [25].

One-leg standing time with eyes open was measured using a digital stopwatch. The participants were asked to stand on one leg (whichever side they preferred), and the measurement began when they lifted their feet. The upper limit was set at 120 s. The time was recorded by setting the end criterion as when both feet were on the ground, when the participants were supported as they were about to fall, when the raised foot touched the opposite foot, or when the foot on the ground moved. Measurements were taken once on each side, and the sum of the left and right values was used as the one-leg standing time with eyes open.

The maximum walking speed was measured using a digital stopwatch. The participants were asked to walk a distance of 11 m on level ground at a fast pace, and the time required to cover the middle 5 m distance was observed. The test was performed twice, and the fastest walking speed was used for analysis.

To assess cognitive function, a face-to-face evaluation was conducted following the MMSE. The MMSE is reported to have intra-rater reliability and is widely used worldwide [26]. In this study, the Japanese version of the MMSE was used, and the usefulness of the assessment has been demonstrated in the Japanese version of the MMSE [27]. Moreover, it is a 30-point questionnaire consisting of 11 items, with higher scores (≥ 24) indicating higher cognitive function and lower scores (≤ 23) indicating cognitive impairment [28].

Statistics analysis

The participants were first divided into two groups for statistical analysis: with and without assistance in standing up. Then, basic information, physical function, and cognitive function were compared using the $\chi 2$ test, t-test, Mann–Whitney test, and Fisher's exact probability test. Binomial logistic regression analysis was also conducted with assisted and unassisted stand up as dependent variables and toe pressure strength in the standing position as the independent variable. In Model 2, the analysis was conducted with toe grip strength as the independent variable. In Model 3, toe pressure strength in the standing position and toe grip strength were added as independent variables, and knee extension strength, maximum walking speed, sex, age, and level of long-term care required were analyzed as covariates to adjust for confounding in the association between them and the presence of assistance in standing up. The model $\chi 2$ test was checked to determine if the model could be used. The goodness-of-fit of the logistic regression equation was also checked using the Hosmer–Lemeshow test and a variance inflation factor (VIF) was calculated to avoid multicollinearity. The statistical significance level was set at 5% ($p < 0.05$). SPSS (version 28.0, IBM, Armonk, NY, USA) was used for analysis.

Results

Participants analyzed in this study

A flowchart of the participants analyzed in this study is shown in Fig. 2. A total of 137 people participated in the physical fitness test, of whom 57 were middle-aged or older adults living in the community and 80 underwent day-care rehabilitation services. We excluded middle-aged adults who met the exclusion criteria, including those aged 64 years or younger ($n = 37$), those who needed assistance in walking ($n = 4$), and those who had missing values in the assessment items ($n = 1$). There were no participants with paralysis or fractures that would affect the measured values and participants who had difficulty standing up even with assistance. As a result, the analysis of this study included 95 community- dwelling older adults (82 ± 8 years old, 72% female) (Fig. 2).

Characteristics of the analyzed participants

Table 1 shows the characteristics of the analyzed participants. There were 59 patients (81 ± 8 years, 69% female) in the non-assisted group and 36 patients (84 ± 7 years, 75% female) in the assisted group. Basic information, physical function, and cognitive function were compared between the groups. The results showed that the assisted group comprised significantly older adults ($p = 0.015$, effect size [ES] = 0.53) and more long-term care certified individuals ($p < 0.001$, ES = 0.45) than the non-assisted group. The assisted group had weaker toe pressure strength in the standing position ($p = 0.015$, ES = 0.53), toe grip strength ($p = 0.017$, ES = 0.48), hand grip strength ($p = 0.005$, ES = 0.61), and knee extension strength ($p < 0.001$, ES = 0.83) than the non-assisted group. The assisted group had shorter one-leg standing time with eyes open ($p = 0.007$, ES = 0.49) and slower maximum walking speed ($p < 0.001$, ES = 1.01) than the non-assisted group. On the other hand, there was no significant difference in MMSE scores between the two groups ($p = 0.068$, ES = 0.19) (Table 1).

Association between the presence of assistance in standing up and toe pressure strength in the standing position

Table 2 shows the results of a binomial logistic regression analysis with the presence of assistance in standing up from a chair as the dependent variable. Model 1 showed that toe pressure in the standing position (odds ratio [OR] 0.97 [0.94–0.99, $p = 0.018$]) was significantly associated with the presence of assistance in standing up. The OR of toe pressure strength in the standing position to "with standing assistance" was less than 1. In addition, Model 2 showed that toe grip strength (OR 1.06 [1.01–1.11, $p = 0.032$]) was significantly associated with the presence of assistance in standing up. The OR of toe grip strength to "with standing assistance" was greater than 1. In Model 3, both toe pressure strength in the standing position (OR 0.94 [0.88–0.99, $p = 0.024$]) and toe grip strength (OR 1.22 [1.06–1.40, $p = 0.006$]) were significantly associated with the presence of assistance in standing up. Note that there were no variables that would result in VIF ≥ 5 among the independent variables. The model $\chi 2$ test for the final model had a p value less than 0.001, the Hosmer–Lemeshow test had a p value equal to 0.438, and the judgmental success rate was 75.8% (Table 2).

Discussion

This study aimed to determine the association between the presence of assistance in standing up and toe pressure strength in the standing position in older adults. Additionally, the degree of association was compared with toe grip strength. First, we compared each measure based on the presence of assistance in standing up from a chair. The results showed that older adults who did not require assistance in standing up had stronger toe pressure in the standing position, toe grip strength, hand grip strength, and knee extension strength; longer one-leg standing time with eyes open; and faster walking speed than older adults who required assistance. As mentioned previously, muscle strength is the most important component of physical function in the standing up movement [7]. In the present study of older adults, a similar trend was observed in the non-assisted group, revealing a characteristic of strong muscle strength. Balance ability has also been reported to be related to the standing up movement [29]. Therefore, the results of this study, which found a significant difference in one-leg standing time with eyes open, are reasonable. Furthermore, walking speed has been described as a vital sign in older adults and is one of

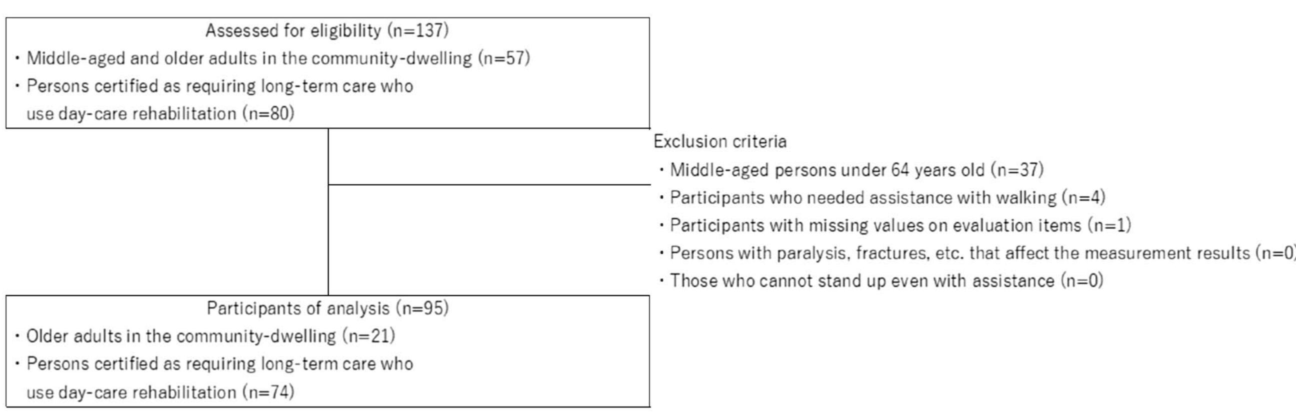

Fig.2 Participants of analysis and exclusion criteria

Table 1 Characteristics of participants of analysis

	All participants (n = 95)	Groups without stand up assistance (n = 59)	Group with stand up assistance (n = 36)	p value	ES	95%CI	
						Lower	Upper
Sex							
Female n (%)	68 (72%)	41 (69%)	27 (75%)	0.564[a]	0.06	− 0.17	0.26
Age (years)	82 ± 8	81 ± 8	84 ± 7	0.015[b]	0.53	0.10	0.95
Height (cm)	151.1 ± 9.4	151.8 ± 10.2	150.0 ± 8.2	0.352[b]	0.20	− 0.22	0.62
Weight (kg)	52.5 ± 10.5	53.8 ± 11.1	50.0 ± 9.0	0.086[b]	0.37	− 0.05	0.79
BMI (kg/m^2)	22.7 ± 3.5	23.1 ± 3.9	22.1 ± 2.7	0.180[b]	0.26	− 0.15	0.68
Level of long-term care required							
No certification n (%)	21 (22%)	21 (36%)	0 (0%)	< 0.001[d]	0.45	0.38	0.60
Support 1 n (%)	23 (24%)	14 (24%)	9 (25%)				
Support 2 n (%)	33 (35%)	16 (27%)	17 (47%)				
Care 1 n (%)	14 (15%)	6 (10%)	8 (22%)				
Care 2 n (%)	3 (3%)	2 (3%)	1 (3%)				
Care 3 n (%)	1 (1%)	0 (0%)	1 (3%)				
Toe pressure in standing position (kgf)	29.4 ± 16.9	32.6 ± 17.0	23.9 ± 15.6	0.015[b]	0.53	0.10	0.95
Toe grip strength (kgf)	13.2 ± 9.3	14.9 ± 10.2	10.5 ± 7.1	0.017[b]	0.48	0.05	0.90
Hand grip strength (kg)	39.8 ± 13.7	42.8 ± 13.3	34.8 ± 12.9	0.005[b]	0.61	0.18	1.03
Knee extension strength (kgf)	29.3 ± 14.7	33.4 ± 14.8	22.1 ± 11.3	< 0.001[b]	0.83	0.40	1.26
Open-eyed one-leg stand time (seconds)	22 ± 37	29 ± 45	11 ± 7	0.007[b]	0.49	0.07	0.92
Max gait speed (m/s)	1.1 ± 0.4	1.2 ± 0.4	0.8 ± 0.3	< 0.001[b]	1.01	0.56	1.46
MMSE (points)	26 (23–28)	26 (24–29)	25 (23–28)	0.068[c]	0.19	–	–

Number (%), mean ± SD, median (1st quartile 3rd quartile)

BMI body mass index, *MMSE* mini-mental state examination, *ES* effect size, *95% CI* 95%confidence interval

[a]χ-square test

[b]*t*-test

[c]Mann–Whitney test

[d]Fisher's exact probability test

the indicators of health status [30]. Based on previous studies, older adults who do not need assistance in standing may be physically healthier than those who require assistance.

Binomial logistic regression analysis revealed that toe pressure strength in the standing position was associated with the presence of assistance in standing up. The OR of toe pressure strength in the standing position to "with standing assistance" was less than 1. On the other hand, although toe grip strength was also significantly associated in Model 2, the OR of toe grip strength to "with standing assistance" was greater than 1. Furthermore, in the final model, toe pressure strength in the standing position and toe grip strength were added as independent variables, and the model was adjusted for covariates. With regard to the selection of covariates, knee extension strength was input, as many reports confirmed the importance of knee extension strength when standing up [7, 31]. Additionally, maximum walking speed has been shown to be a vital sign of the body [30], and age, sex and level of long-term care required [32] were entered as covariates in the final model, as they were considered to be demographic variables associated with the presence or absence of assistance in standing up. The results showed that toe pressure strength in the standing position and toe grip strength were both significantly associated. However, the ORs differed for each. In other words, the stronger the toe pressure strength in the standing position, the more likely older adults required "no" assistance in standing up. On the other hand, toe grip strength may not be related to "no" assistance in standing up. Maximum walking speed, which was entered as a covariate in the final model, was also significantly related to the presence or absence of assistance in standing up. The results of this study, in which maximum walking speed was associated to the presence of assistance in standing up, are valid, given that walking speed is described as a vital sign of the body [30]. An important result we would like to argue here is that even in the final model with maximal walking speed input, toe pressure strength in the standing position was significantly associated with the presence of assistance in standing up. The odds ratio of toe pressure strength in the standing position to the

Table 2 Association between the presence of assistance in standing up and toe pressure strength in the standing position

	Partial regression coefficient	OR (95%CI)	*p* value	VIF
Model 1				
Toe pressure in standing position	− 0.03	0.97 (0.94–0.99)	0.018	
Model-χ-squared test			0.013	
Hosmer–Lemeshow test			0.381	
Model 2				
Toe grip strength	0.56	1.06 (1.01–1.11)	0.032	
Model-χ-squared test			0.023	
Hosmer–Lemeshow test			0.748	
Model 3				
Toe pressure in standing position	− 0.07	0.94 (0.88–0.99)	0.024	2.52
Toe grip strength	0.20	1.22 (1.06–1.40)	0.006	3.96
Knee extension strength	− 0.06	0.95 (0.89–1.00)	0.067	2.16
Maximum walking speed	− 3.37	0.03 (0.00–0.33)	0.004	2.59
Sex	− 0.34	0.71 (0.19–2.70)	0.618	1.22
Age	0.05	1.05 (0.97–1.14)	0.264	1.41
Level of long-term care required	0.49	1.63 (0.94–2.84)	0.084	1.51
Model-χ-squared test			< 0.001	
Hosmer–Lemeshow test			0.438	

Binomial logistic regression analysis

Each model, Groups without stand up assistance (0) and Group with stand up assistance (1) are set as the dependent variables

Model 1: Judgmental success rate 62.1%

Model 2: Judgmental success rate 61.7%

Model 3: Model with knee extension strength, maximum walking speed, sex, age, and level of long-term care required as covariates, Judgmental success rate 75.8%

OR odds ratio, *95% CI* 95% Confidence interval, *VIF* variance inflation factor

presence of assistance in standing up was 0.94. Converting this to an inverse number yields 1.06. Therefore, a 1 kgf increase in toe pressure strength in the standing position can be interpreted leading to an odds of 1.06 for standing up without assistance.

The rise motion consists of four phases: flexion phase, momentum transfer phase, extension phase, and stabilization phase [33]. In the momentum transfer phase, the center of gravity must be shifted horizontally and vertically from the thigh to the leading edge of the foot; then, the body weight must be supported [34]. In other words, during the momentum transfer phase, the center of gravity must shift to the toes, and the body weight must be supported by compressing the floor surface. This ability is considered to be one of the factors that facilitate standing up. We speculate that the movements comprising the rising motion may be a factor in the association with toe pressure strength in the standing position. In fact, a previous study found that moving the center of pressure forward of the foot facilitates standing up [35], which supports the discussion of the present results. The strength of the toe muscles, which support the body while pressing down on the floor after the center of pressure is moved to the front of the foot, may be a function of whether or not the patient needs assistance in standing up. Toe pressure strength in the standing position evaluates the muscular strength to compress the floor surface without flexing the toes. This method is similar to short foot exercise (SFE), which strengthens the intrinsic muscles of the foot. The SFE directs the movement to bring the toes and heel closer together while pressing down on the floor without flexing the toes [36, 37]. In other words, although this study is speculative, toe pressure strength in the standing position may reflect the intrinsic muscle strength of the foot. The intrinsic muscles of the foot have been reported to contribute to many improvements in balance ability [38, 39]. On the other hand, previous studies have shown that toe grip strength does not reflect balance ability [35, 40]. Since rising from a chair reflects dynamic balance ability [41], we infer that only toe pressure strength in the standing position, which is presumed to assess the intrinsic muscles of the foot, showed a favorable association with rising from a chair. Furthermore, the momentum transfer phase is the phase with the greatest load during the rising motion of older adults [42]. A study in a nursing home also reported that approximately 41% of falls during the standing up phase occurred in the momentum transfer phase [43]. Although further validation is needed in future, the results suggest that interventions for improving toe pressure strength in the standing position may also contribute in the prevention of falls when standing up.

Two interesting points became clear in this study. The first point is that toe pressure strength in the standing position was more associated with the presence of assistance in standing up than with knee extension strength. Tests involving standing up, such as the 30-s chair stand test and the 5 Times Sit-to-Stand Test, have generally been found to be associated with knee extension strength [44, 45]. On the other hand, this study examined physical functions associated with the presence of assistance in standing up from a chair in older adults and found an associated with toe pressure strength in the standing position. Although a direct association cannot be addressed in this study, the phases involving knee extension strength in the rising motion and toe pressure strength in the standing position may be different. The second point is that toe pressure strength in the standing position was more associated with the presence of assistance in standing up than toe grip strength. As mentioned earlier, the ORs for the presence of assistance in standing up were different. In other words, even if toe grip strength was strong, it was not associated with "no" assistance in standing up. Furthermore, this association may inform future intervention strategies. The similarity between SFE and the method of measuring toe pressure in the standing position may solve the difficulty of SFE intervention. Although further research is needed, the measurement device used in this study could be used to provide strength training to strengthen the intrinsic muscles of the foot while using visual feedback. The strength of this study is that it is the first study to determine the association between toe pressure strength in the standing position and the presence of assistance during standing up movements in older adults. Another strength is that this study showed that toe pressure strength in the standing position may have greater contribution than toe grip strength with respect to the presence of assistance in standing up.

This study has several limitations. The first is that the sample size was small. In order to generalize the results, more people need to be examined in the analysis. In addition, this study examined physical functions related to the presence of assistance in standing up with limited variables. As older adults with reduced muscle strength use their trunk dynamically to facilitate standing up, older adults who have difficulty standing up have learned to stand up in a way that is not dependent on muscle strength [46]. Future studies should incorporate a variety of variables related to standing up in older adults, not only muscle strength but also joint torque. Furthermore, specific assistance tools were not evaluated for older adults who needed assistance when standing up. Finally, since this is a cross-sectional study, it is not possible to mention causal relationships. In future, longitudinal studies are needed. However, this is the first study to clarify the association between the strength of toe pressure strength in the standing position and the presence of assistance during standing up movements in older adults, and it will contribute to future rehabilitation.

This study revealed that toe pressure strength in the standing position is associated with the presence of assistance in standing up in older adults. On the other hand, toe grip strength was negatively associated with no assistance in standing up in older adults. The results suggested that toe pressure strength in the standing position may improve standing movements in older adults who have difficulty standing up. Moreover, toe pressure strength in the standing position may be one of the important muscular forces among those associated with standing up. One factor associated with the presence of assistance in standing up may be the need to assess toe pressure strength in the standing position.

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Author contributions Since we work as a team, essentially all authors are involved in planning the study, conducting the study, and reviewing it after it is written. Roles with particular contributions are listed below. Conceptualization, Methodology, Formal analysis, Investigation, Data Curation & Writing—Original Draft: TK, Conceptualization, Investigation, Data Curation & Supervision: TT, Methodology, Investigation & Data Curation: MH, Investigation & Data Curation: ST, Validation & Writing—Review & Editing: TK, Validation & Writing—Review & Editing: KO, Formal analysis & Project administration: SS, Methodology, Formal analysis & Project administration: MM, Validation & Writing—Review & Editing: GH, Conceptualization, Investigation, Data Curation & Supervision: HO.

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Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest There are no conflicts of interest to disclose in this study.

Ethical approval The study was approved by the Ethical Review Committee of Nishikyushu University, where the responsible author is affiliated (approval number: 22FZX09).

Informed consent All participants provided informed consent.

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