Paper

Ground Reaction Force in Sit-to-Stand Movement reflects Lower Limb Function in Middle-Aged and Older Women with Knee Pain

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Purpose: The aim of the present study was to elucidate the reliability and validity of measurement of ground reaction force (GRF) parameters during a sit-to-stand (STS) movement as a method of assessing lower limb muscle function in middle-aged and older women with knee pain. Methods: We recruited 61 women with mild to moderate knee pain and 61 healthy controls, aged 50–86 years. Five GRF parameters were measured: peak reaction force, two rate of force development parameters, and two time-related parameters. These parameters were compared on the basis of the presence or absence of knee pain. Intraclass correlation coefficients (ICC) and errors of measurement values were calculated. Partial correlation analysis adjusted for age was used to investigate the association between GRF parameters and knee extension strength, muscle power, and five physical function tests. Results: Significant differences were observed between groups in the following GRF parameters: peak reaction force and the two parameters of force development rate (Cohen's d = 0.68–1.44). In participants with knee pain, the abovementioned three parameters had a good reproducibility (ICC = 0.88–0.93). The two parameters of force development rate were significantly correlated with knee extension torque and power (partial-r = 0.50–0.57) and five physical function tests (partial-$|r|$ = 0.40–0.59) adjusted for age. Conclusion: These results suggested that GRF parameters in the STS movement have sufficient reliability and validity as a method of assessment of lower limb muscle function in middle-aged and older women with mild to moderate knee pain.

Key words : knee osteoarthritis; muscle strength; muscle power; physical function test

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1. Introduction

Approximately 60%–70% of middle-aged and older Japanese women suffer from degenerative arthritis of knees, and approximately 30%–40% experience knee pain (Muraki et al., 2009). The onset and progression of knee osteoarthritis are closely related to decreased muscle function in the lower limbs, primarily in muscle strength and power around the knee joint, accompanied by limited mobility (Fransen and McConnell, 2008). A highly reliable and valid method is required to detect decreased lower limb muscle function at an early stage of the disease and to understand the effects of any preventive and remedial measures that may be implemented.

Recent reports (Lindemann et al., 2003; Tsuji et al., 2011; 2015; Yamada and Demura, 2010) have shown vertical ground reaction force (GRF) parameters in a sit-to-stand (STS) movement to be useful for evaluating lower limb muscle function with good test–retest reliability and criterion-related validity in middle-aged and older adults. The benefits of this method are as follows: assessment of the force output during daily activities, direct measurement of the force output in "kilogram–force (kgf)" using the force platform, ability to measure a person who is able to perform only a few STS movements, and relative ease of transporting the measurement instrument (simple force platform) (Tsuji et al., 2015).

Knee extension strength and power play important roles in performing an STS movement (Bassey et al., 1992; Schenkman et al., 1996), thereby affecting knee pain. The tests have both advantages, such as accurately reflecting decreased lower limb muscle function induced by knee pain, and disadvantages, such as low reproducibility and poor validity. Although several previous reports examined the potential impact of knee pain during isometric muscle strength testing (Mizner et al., 2005; Riddle and Stratford, 2011; Stevens et al., 2003), those results were not in accord with each other. In one study, the authors found that the knee pain had a small but statistically significant influence on lower limb muscle activation (Stevens et al., 2003), whereas no influence was found in the other two studies (Mizner et al., 2005; Riddle and Stratford, 2011). Therefore, the present study aimed to investigate whether measurement of GRF parameters during an STS movement can be applied as a method of assessing lower limb muscle function for middle-aged and older women with knee pain. To achieve this aim, cases were compared for the presence or absence of knee pain to confirm whether decreased lower limb muscle function accompanying knee pain was reflected in GRF parameters during the STS movement. Furthermore, reproducibility of measurement values and errors were estimated, and criterion-related validity was clarified for knee extension strength, muscle power, and physical function tests.

2. Materials and Methods

2.1. Participants

In the present study, the power analysis with settings at $\alpha = 0.05$ and $1-\beta = 0.80$ showed that total 46 participants was the required sample size to detect a moderate to strong significant correlation ($|r| \geq 0.40$). We performed the power analysis using G*Power 3.1.3 (University of Kiel, Kiel, Germany). Baseline data were recorded for subjects who participated in exercise programs designed to relieve knee pain and improve knee function at our University. A flowchart showing the progress of participants from recruitment and selection to test completion is shown in Figure 1. Participants were recruited via advertisements published in local information magazines with responses conducted over the telephone. The inclusion criterion was postmenopausal women with knee pain. Exclusion criteria are shown in Figure 1. Sixty-one women (age: 50–86 years) underwent all parameter measurements and were assigned to the knee pain group. For 32 of the participants, GRF parameters were measured twice with a 2-min interval to assess reproducibility because measurements could not be conducted twice in all participants due to schedule constraints. There were no significant differences in any variables between 32 women for assessing reproducibility and the other 29 women. The control group consisted of 61 age and body mass index-matched women without knee pain who participated in other exercise programs held at the University or health care center.

This study was conducted with the approval of the ethics committee of the University of Tsukuba. All participants received both oral and written explanations of this study and their written consent was obtained.

2.2. Measurement variables

2.2.1. GRF parameters and degree of knee pain in the STS movement

We measured GRF parameters in the STS movement with maximum exertion using the force plate (TKK5809, Takei Scientific Instruments Co., Ltd., Niigata, Japan) and calculated five GRF parameters (Figure 2) as in previous studies (Tsuji et al., 2011; 2015): the peak reaction force per body weight (F/w, $kgf \cdot kg^{-1}$), maximal rate of force development (RFD; Δ10 ms) per body weight (RFD1/w, $kgf/s \cdot kg^{-1}$) defined as the steepest gradient of the force–time curve over a given 10-ms time period, RFD9/w ($kgf/s \cdot kg^{-1}$) with a sample duration of 90 ms, time span of the developing force (T1, ms), and chair-rise time (T2, ms).

The degree of knee pain was investigated during the first STS movement using a 100-mm visual analogue scale (VAS) on the more affected knee. Thirty-two women repeated the test after a 2-min rest period to assess reproducibility.

2.2.2. Knee extension peak torque and average power

A Biodex System 3 isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA) was used to test

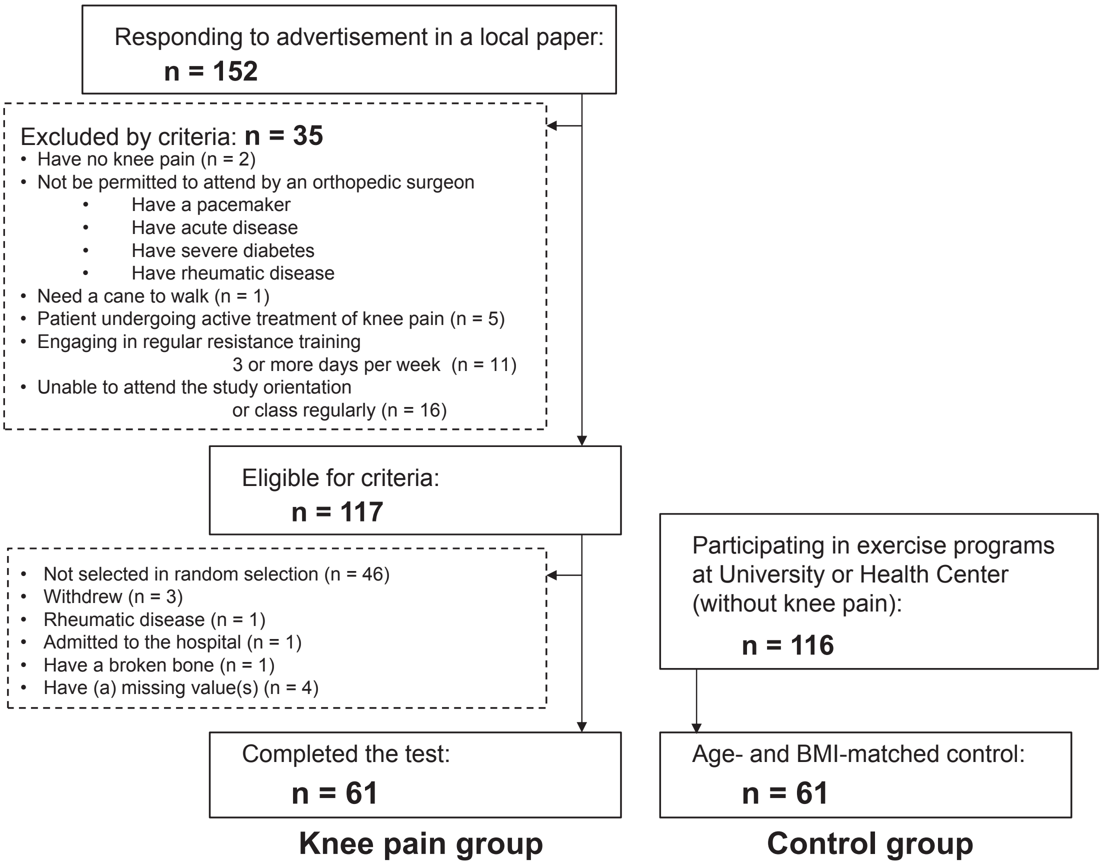

Figure 1. The flow of participants through the study.

knee extension isometric (0°/s) and isokinetic (60°/s) peak torques and isokinetic (60°/s) average power in both legs. Participant positioning and protocol measurement for the knee extension trials have been previously described (Symons et al., 2005; Tsuji et al., 2015). Torque and power data from each leg were totaled and normalized per kilogram of body weight (Nm/kg and W/kg, respectively).

2.2.3. Physical function tests

Similar to a previous study (Tsunoda et al., 2013), we assessed the following five physical function tests that play critical roles in muscle exertion around the knee joint area or upper limb: grip strength, 5-m habitual walk, timed "up and go" (TUG), standing time from a long sitting position, and choice reaction time.

2.2.4. Other variables

To estimate the degree of knee pain of participants, we used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (Bellamy et al., 1988) pain subscale and evaluated the strongest pain in the more affected knee experienced by participants within a few days using the 100-mm VAS in the knee pain group.

2.3. Statistical analyses

A Student's *t*-test was performed to compare the means of GRF parameters between groups and was calculated as per Cohen's *d* effect sizes (Cohen, 1988). The intraclass correlation coefficient [ICC (1,1)] was calculated to quantify the reproducibility of GRF parameters, and a one-way analysis of variance was conducted to examine the difference between paired values. ICC values ≥0.70 were classified as good (Currier, 1990). To estimate measurement error, we calculated the standard error of measurement (SEM) (Haley and Fragala-Pinkham, 2006) and minimal detectable change (MDC) (Faber et al., 2006) using the following formulae:

$\mathrm{SEM} = \mathrm{SD}_d/\sqrt{2}$

$\mathrm{MDC} = 1.96 \times \mathrm{SD}_d$

(SD_d: standard deviation of difference between paired measures)

Partial correlation analyses (adjusted for age) were conducted to examine relationships between GRF parameters and knee extension peak torque, average

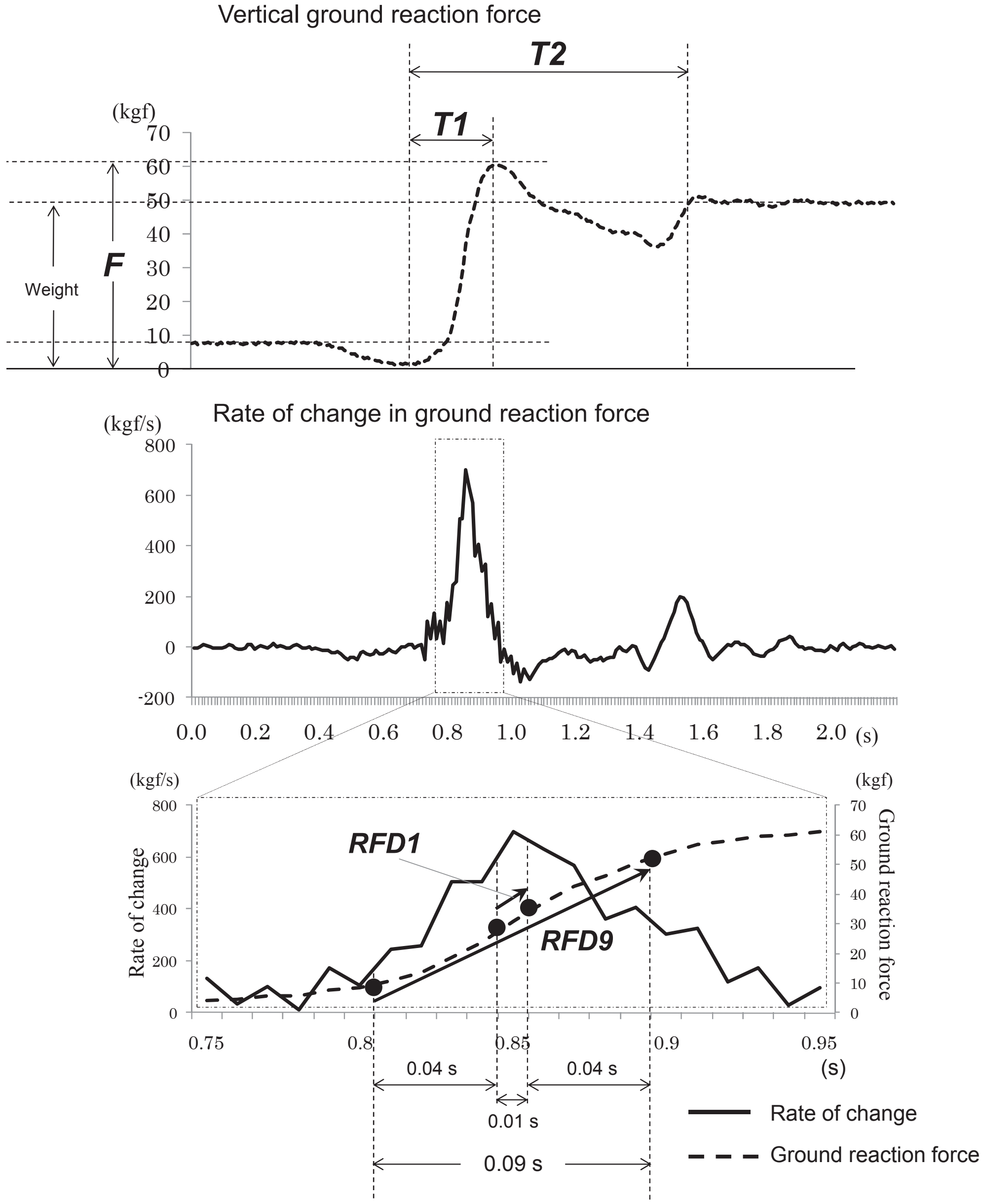

Figure 2. Ground reaction force parameters. F: peak reaction force; RFD1: the maximal rate of force development (Δ10 ms); RFD9: the maximal rate of force development (Δ90 ms); T1: time span of the developing force; T2: chair-rise time.

power, and physical function tests values. Spearman's ρ was calculated to examine relationship between GRF parameters and pain scales. All analyses were conducted using IBM SPSS Statistics 17.0 (IBM Corp., NY, USA). The level of significance was set at $P < 0.05$.

3. Results

Table 1 shows the descriptive data for all participants and the results of the comparison of GRF parameters between groups. We observed significant differences and middle/large effects in all GRF parameters, except in T1. The degree of knee pain felt by participants during the STS movement testing tended to be milder compared with that felt in the days before. Twenty-nine women (47.5%) felt no pain during the STS movement testing.

Table 2 shows ICC, SEM, and MDC values of each GRF parameter in the knee pain group. All GRF parameters (except T1) demonstrated good reproducibility (ICC ≥ 0.70).

Partial correlation coefficients (adjusted for age) between GRF parameters and knee extension peak torque,

Table 1. Characteristics, ground reaction force parameters, knee extension variables, and physical function tests' results of the participants by group and the results of group comparison

		Knee pain n = 61	Control n = 61		
		Mean (SD)	Mean (SD)	*P*	*d*
Characteristics					
Age	(year)	66.8 (6.9)	66.8 (6.9)	1.000	< 0.01
Height	(cm)	153.2 (5.2)	152.0 (4.9)	0.180	0.24
Body weight	(kg)	56.1 (8.8)	55.6 (7.4)	0.740	0.06
body mass index	(kg/m^2)	24.1 (3.5)	24.1 (3.1)	0.970	0.01
Affected side	bilateral; n (%)	22 (36.1%)	–		
WOMAC pain	(point)	3.2 (2.6)	–		
100-mm VAS[a]		30.2 (25.3)	–		
Ground reaction force parameters and knee pain during STS test					
F/w	($kgf\cdot kg^{-1}$)	1.30 (0.10)	1.37 (0.09)	< 0.001	0.68
RFD1/w	($kgf/s\cdot kg^{-1}$)	10.88 (2.28)	15.12 (3.50)	< 0.001	1.44
RFD9/w	($kgf/s\cdot kg^{-1}$)	9.08 (1.67)	10.57 (1.55)	< 0.001	0.93
T1	(ms)	317 (83)	302 (77)	0.320	0.18
T2	(ms)	908 (192)	814 (128)	0.002	0.58
100-mm VAS[a] during STS test		9.7 (13.4)	–		
Knee extension peak torque and average power					
Isometric peak torque	(Nm/kg)	2.98 (0.73)	–		
Isokinetic peak torque	(Nm/kg)	2.23 (0.70)	–		
Isokinetic average power	(W/kg)	1.21 (0.43)	–		
Physical function tests					
Grip strength	(kg)	24.1 (3.9)	–		
5-m habitual walk	(s)	3.8 (0.6)	–		
Timed "up and go"	(s)	5.9 (0.8)	–		
ST-LSP	(s)	3.1 (1.0)	–		
Choice reaction time	(ms)	984 (104)	–		

a: scored according to more affected knees.

Note. SD: standard deviation, STS: sit-to-stand movement, WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index, VAS: visual analogue scale, F: peak reaction force, RFD1: maximal rate of force development (Δ10 ms), RFD9: maximal rate of force development (Δ90 ms), T1: time span of the developing force, T2: chair-rise time, w: body weight, ST-LSP: standing time from a long sitting position.

average power, and physical function tests are listed in Table 3. Among the knee pain group participants, all GRF parameters except for T1 had significant correlations with knee extension torque and power variables. Moderate significant partial correlations with TUG, standing time from a long sitting position, and choice reaction time results were evaluated for all GRF parameters. We observed weak correlations between all GRF parameters and all pain scales (Table 3).

4. Discussion

The mean WOMAC pain score for the knee pain group in this study was 3.2 (worst: 20), and the mean 100-mm VAS was 30.2 (worst: 100). Patients with extreme pain were not included because subjects participated in the exercise class of their volition, and only those subjects who were given permission for safe research participation by an orthopedic surgeon were included.

We found that participants with knee pain exhibited lower scores for variables evaluated in force units. This suggests that participants were not stepping down firmly and quickly while performing the STS movement. This may be due to decreased knee extension strength and an inability to exert full force while standing. Because maximum knee extension torque and average power were not measured in the control group, the groups could not be directly compared. However, a previous study (Hassan et al., 2001) reported that patients with knee osteoarthritis have 35% lower isometric knee extension strength compared with those of healthy subjects. Furthermore, electrical stimulation of muscles leads to a mean ratio

Table 2. Within-run reproducibility and measurement error of each parameter in the knee pain group (n = 32)

Variable	1st trial	2nd trial	Within-run reproducibility		Measurement error	
	Mean (SD)	Mean (SD)	P^a	ICC (1, 1)	SEM	MDC
F/w (kgf·kg^{-1})	1.31 (0.08)	1.30 (0.09)	0.087	0.93	0.02	0.06
RFD1/w (kgf/s·kg^{-1})	11.18 (1.77)	11.11 (1.78)	0.595	0.92	0.52	1.45
RFD9/w (kgf/s·kg^{-1})	9.27 (1.29)	9.23 (1.28)	0.760	0.88	0.45	1.23
T1 (ms)	318 (75)	306 (58)	0.308	0.46	49	137
T2 (ms)	898 (154)	891 (149)	0.681	0.81	66	184

a: *P* for 1-way ANOVA.

Note. SD: standard deviation, ICC: intra-class correlation, SEM: standard error of measurement, MDC: minimal detectable change, F: peak reaction force, RFD1: maximal rate of force development (Δ10 ms), RFD9: maximal rate of force development (Δ90 ms), T1: time span of the developing force, T2: chair-rise time, w: body weight.

Table 3. Partial correlation[a] (partial-*r*) and correlation (*ρ*) coefficients between ground reaction force parameters, and peak torque and average power, physical function tests results, and pain scalses in the knee pain group (n = 61)

Variable	F/w		RFD1/w		RFD9/w		T1		T2	
Knee extension torque and power	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*
Isometric (0 deg/s) peak torque	0.58	< 0.001	0.57	< 0.001	0.55	< 0.001	-0.28	0.032	-0.44	0.001
Isokinetic (60 deg/s) peak torque	0.49	< 0.001	0.54	< 0.001	0.52	< 0.001	-0.23	0.075	-0.45	< 0.001
Isokinetic (60 deg/s) average power	0.45	< 0.001	0.52	< 0.001	0.50	< 0.001	-0.17	0.205	-0.41	0.001
Physical function tests	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*	pratial-*r*	*P*
Grip strength	0.46	< 0.001	0.40	0.002	0.40	0.002	-0.38	0.003	-0.36	0.005
5-m habitual walk	-0.34	0.010	-0.47	< 0.001	-0.46	< 0.001	0.31	0.018	0.36	0.005
Timed "up and go"	-0.45	< 0.001	-0.59	< 0.001	-0.59	< 0.001	0.56	< 0.001	0.63	< 0.001
Standing time from a long sitting position	-0.47	< 0.001	-0.56	< 0.001	-0.56	< 0.001	0.49	< 0.001	0.59	< 0.001
Choice reaction time	-0.53	< 0.001	-0.47	< 0.001	-0.48	< 0.001	0.46	< 0.001	0.43	0.001
Pain scales	*ρ*	*P*	*ρ*	*P*	*ρ*	*P*	*ρ*	*P*	*ρ*	*P*
WOMAC pain	0.25	0.051	0.32	0.011	0.29	0.022	0.24	0.059	0.26	0.044
100-mm VAS (within a few days)	0.29	0.023	0.29	0.022	0.30	0.018	0.20	0.119	0.24	0.065
100-mm VAS (during STS movement)	0.29	0.024	0.34	0.007	0.33	0.009	0.27	0.034	0.28	0.029

a: adjusted for age.

Note. F: peak reaction force, RFD1: maximal rate of force development (Δ10 ms), RFD9: maximal rate of force development (Δ90 ms), T1: time span of the developing force, T2: chair-rise time, w: body weight, WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index, VAS: visual analogue scale, STS: sit-to-stand.

of maximum voluntary muscle strength to maximum estimated physiological muscle strength of 87.4% in healthy subjects compared with 66.0% in patients with knee osteoarthritis. Therefore, patients with knee osteoarthritis are likely not exerting their full muscle strength (Hassan et al., 2001).

The present study showed that GRF parameters measured in force units exhibited an overall high ICC, confirming excellent reproducibility. Furthermore, Consensus-based Standards for the Selection of Health Measurement Instruments (Mokkink et al., 2010) recommends showing error indices, such as SEM and MDC. One reason for maintaining evaluation index quality is that the minimally important difference (change) used to indicate clinical significance is greater than MDC (Terwee et al., 2007). Therefore, when differences observed in the present study were considered to be minimally important differences, each value in force unit was greater than MDC. These measurement differences may not be due to measurement error. Accordingly, this evaluation method sufficiently reflects decreased lower limb function accompanying knee pain.

We observed a moderately significant correlation between the two RFD variables with knee extension torque, average power, and all physical function tests. This suggests that even when participants have knee pain, GRF parameters in an STS movement can maintain criterion-related validity for these parameters. A previous study involving healthy older participants (Tsuji et al., 2011) indicated significant age-adjusted partial correlations between RFD9/w, TUG, standing time from a long sitting position, and choice reaction time. The present study also indicated a similar correlation. Riddle and Stratford (2011) found that although significant correlations were observed between the isometric knee extension strength, 5-times standing time, and 20- and 400-m walking test scores, there was no correlation with pain intensity. Therefore, when subjects experience pain during muscle strength measurement, correlations with physical function are not affected, thereby maintaining the validity of the evaluation method.

In the present study, the two RFD variables that had good reproducibility and validity are suitable measures in clinical settings for people with knee pain. These findings are consistent with a previous study with community-dwelling healthy older adults (Tsuji et al., 2011; 2015). They reported that RFD9/w showed high reproducibility and significance with knee strength and power, physical functions, history of falls, and mobility limitation and concluded that it is the most important GRF parameter for evaluating lower extremity function. On the contrary, time-related parameters (T1 and T2) had relatively low reliability and validity, especially T1 showed poor reproducibility, no significant difference between groups and weak relationships with knee extension torque and power in the present study. Poor reproducibility of T1 might be caused by the instability of appearance timing of peak reaction force. Duffell and colleagues (2013) evaluated weight distribution during STS movement in patients with early knee osteoarthritis, and found an imbalance between GRF from affected and unaffected sides in the standing phase (i.e., from seat off to standing position). Because peak reaction force is recorded in that phase with unsteady force output, we can neither obtain stable value nor observed criterion-related validity in T1.

The main limitations of this study are as follows: the study had low generalizability due to the small sample size although a sample size greater than 100 is recommended (Mokkink et al., 2010); and correlation analysis was conducted without performing multivariate analyses, such as multiple regression. Furthermore, maximum knee extension torque and average power and physical function tests were not measured in the control group. Therefore, we could not figure out how different the sizes of differences in GRF parameters and in those measurements between groups were. We also could not compare the degree of relationship of GRF parameters with those measurements between groups. Lastly, there is still room for discussion about the impact of knee pain on measurement values and on validity of this measurement method by the results from the present cross-sectional analyses. Further studies with longitudinal follow-up and investigating associations of change in GRF parameters with onset of knee pain and deterioration of lower limb muscle function are needed to clarify the validity in more detail.

In conclusion, the measurement of GRF parameters during STS movement can be used as a method for evaluating lower limb muscle function in middle-aged and older women with mild to moderate knee pain. Applying this method in future intervention or longitudinal studies will be a novel option of clinical performance tests in the field of physical rehabilitation to estimate its therapeutic effect or in preventive nursing care to screen for sarcopenia, dynapenia, and limited mobility.

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References

Bassey, E.J., Fiatarone, M.A., O'Neill, E.F., Kelly, M., Evans, W.J., and Lipsitz, L.A. (1992) Leg extensor power and functional performance in very old men and women. Clinical Science (London, England :

1979) 82 (3): 321-327.

Bellamy, N., Buchanan, W.W., Goldsmith, C.H., Campbell, J., and Stitt, L.W. (1988) Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. The Journal of Rheumatology 15 (12): 1833-1840.

Cohen, J. (1988) Statistical Power Analysis for the Behavioral Science (2nd ed.), Lawrence Erlbaum Assoc Inc: New Jersey

Currier, D.P. (1990) Elements of Research in Physical Therapy (3rd ed.), Williams & Wilkins: Maryland, pp. 150-171.

Duffell, L.D., Gulati, V., Southgate, D.F., and McGregor, A.H. (2013) Measuring body weight distribution during sit-to-stand in patients with early knee osteoarthritis. Gait & Posture 38 (4): 745-750.

Faber, M.J., Bosscher, R.J. and van Wieringen, P.C. (2006) Clinimetric properties of the performance-oriented mobility assessment. Physical Therapy 86 (7): 944-954.

Fransen, M. and McConnell, S. (2008) Exercise for osteoarthritis of the knee. The Cochrane Database of Systematic Reviews CD004376.

Haley, S.M. and Fragala-Pinkham, M.A. (2006) Interpreting change scores of tests and measures used in physical therapy. Physical Therapy 86 (5): 735-743.

Hassan, B.S., Mockett, S. and Doherty, M. (2001) Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Annals of the Rheumatic Diseases 60 (6): 612-618.

Lindemann, U., Claus, H., Stuber, M., Augat, P., Muche, R., Nikolaus, T., and Becker, C. (2003) Measuring power during the sit-to-stand transfer. European Journal of Applied Physiology 89 (5): 466-470.

Mizner, R.L., Petterson, S.C., Stevens, J.E., Vandenborne, K., and Snyder-Mackler, L. (2005) Early quadriceps strength loss after total knee arthroplasty: The contributions of muscle atrophy and failure of voluntary muscle activation. The Journal of Bone and Joint Surgery. American Volume 87 (5): 1047-1053.

Mokkink, L.B., Terwee, C.B., Patrick, D.L., Alonso, J., Stratford, P.W., Knol, D.L., Bouter, L.M., and de Vet, H.C. (2010) The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: an international Delphi study. Quality of Life Research 19 (4): 539-549.

Muraki, S., Oka, H., Akune, T., Mabuchi, A., En-yo, Y., Yoshida, M., Saika, A., Suzuki, T., Yoshida, H., Ishibashi, H., Yamamoto, S., Nakamura, K., Kawaguchi, H., and Yoshimura, N. (2009) Prevalence of radiographic knee osteoarthritis and its association with knee pain in the elderly of Japanese population-based cohorts: the ROAD study. Osteoarthritis and Cartilage 17 (9): 1137-1143.

Riddle, D.L. and Stratford, P.W. (2011) Impact of pain reported during isometric quadriceps muscle strength testing in people with knee pain: data from the osteoarthritis initiative. Physical Therapy 91 (10): 1478-1489.

Schenkman, M., Hughes, M.A., Samsa, G., and Studenski, S. (1996) The relative importance of strength and balance in chair rise by functionally impaired older individuals. Journal of the American Geriatrics Society 44 (12): 1441-1446.

Stevens, J.E., Mizner, R.L. and Snyder-Mackler, L. (2003) Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. Journal of Orthopaedic Research 21 (5): 775-779.

Symons, T.B., Vandervoort, A.A., Rice, C.L., Overend, T.J., and Marsh, G.D. (2005) Reliability of a single-session isokinetic and isometric strength measurement protocol in older men. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences 60 (1): 114-119.

Terwee, C.B., Bot, S.D., de Boer, M.R., van der Windt, D.A., Knol, D.L., Dekker, J., Bouter, L.M., and de Vet, H.C. (2007) Quality criteria were proposed for measurement properties of health status questionnaires. Journal of Clinical Epidemiology 60 (1): 34-42.

Tsuji, T., Mitsuishi, Y., Tsunoda, K., Yoon, J.Y., Kitano, N., Yoon, J., and Okura, T. (2011) The relationship between ground reaction force in a sit-to-stand movement and physical functioning, history of falls, fear of falling, and mobility limitations in community-dwelling older adults. Japanese Journal of Physical Fitness and Sports Medicine 60 (4): 387-399. [In Japanese, English abstract]

Tsuji, T., Tsunoda, K., Mitsuishi, Y., and Okura, T. (2015) Ground reaction force in sit-to-stand movement reflects lower limb muscle strength and power in community-dwelling older adults. International Journal of Gerontology 9 (2): 111-118.

Tsunoda, K., Soma, Y., Kitano, N., Tsuji, T., Mitsuishi, Y., Yoon, J.Y., and Okura, T. (2013) Age and gender differences in correlations of leisure-time, household, and work-related physical activity with physical performance in older Japanese adults. Geriatrics & Gerontology International 13 (4): 919-927.

Yamada, T. and Demura, S. (2010) The relationship of force output characteristics during a sit-to-stand movement with lower limb muscle mass and knee joint extension in the elderly. Archives of Gerontology and Geriatrics 50 (3): e46-e50.