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Original Article

Accuracy of a portable lower-limb muscle strength measuring device with a training function

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Abstract. [Purpose] Quadriceps muscle strength is essential for daily living activities. Therefore, we developed a compact and simple lower limb muscle strength measuring device (LocomoScan [LCS]). This study aimed to compare LCS with other instruments to analyze its simplicity, reproducibility, and accuracy. [Participants and Methods] One hundred and four healthy university students (56 males and 48 females) were included in the study. The knee extension force was measured using LCS, and the knee extension torque was measured using other devices (Cybex). In addition, lower leg muscle mass was measured using a body composition meter. The reproducibility of LCS and the correlation between the knee extension torque and lower leg muscle mass were evaluated. [Results] The measurement reproducibility of LCS was significantly higher. The knee extension force confirmed the proportional relative reliability of Cybex with knee extension torque. A relationship between knee extension force and lower limb muscle mass was also observed, indicating that muscle mass cannot be estimated as muscle strength. [Conclusion] The high reproducibility of the knee extension force measurement using LCS demonstrates its potential as a portable alternative instrument for muscle strength measurement in clinical practice. Therefore, LCS device is a simple and effective tool for assessing muscle strength.

Key words: Lower leg muscle strength measuring device, Quadriceps muscle strength, Reliability

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INTRODUCTION

Lower limb muscle strength is extremely important for human daily life activities. Furthermore, in an ageing society, lower limb muscle strength is paid attention to in older adults. This is because lower limb muscle strength is a potential alternative indicator for predicting gait speed and falls. In addition, locomotive syndrome is diagnosed based on medical

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*Corresponding author. Atsushi Nawata (E-mail: naat.aith@gmail.com) interviews, a standing test and a two-stage test[1], whereas the diagnosis and severity of sarcopenia is determined by limb muscle mass, grip strength, and walking speed[2, 3]. Both diagnoses require an assessment of lower limb motor function. This assessment does not measure lower limb muscle strength due to the lack of useful devices that can accurately and easily measure lower limb muscle strength in daily life or clinical settings.

Multifunction dynamometers and handheld dynamometers (HHD) are commonly used to measure lower limb muscle strength. Although multifunctional muscle strength measuring devices, such as the Biodex System 4 and Cybex Norm CN77, have excellent accuracy, they are heavy and not portable. Furthermore, older people might find using these devices difficult as they are large and represent a burden for prepare measurements" for more clarity and readability. Although, HHD measures a person's muscle strength manually and is portable, it requires individual to undergo training to perform correct measurements and techniques[4].

Therefore, a simple and accurate measuring device for lower limb muscle strength is essential.

We suggest that there is a need to develop a new measuring device bearing the accuracy of a multifunctional dynamometer and ease of use of an HHD to obtain large and accurate data to create standard values and judgment criteria for lower limb muscle strength. Thus, we developed a small and simple lower limb muscle strength measuring device (QTM-05F, Alcare Co., Ltd., Tokyo, Japan: QTM)[5] by narrowing down the function to measure knee extension force at the position where the quadriceps femoris muscle is located.

Based on this, we developed a smaller product with higher accuracy and operability (Locomote Scan, Alcare Co., Ltd., LCS, Fig. 1). To date, we have not fully examined the reproducibility of this new measurement method, its relevance to large multifunctional dynamometers and relationship with muscle mass.

Therefore, this study aimed to clarify the reproducibility of LCS, its correlation with large multifunctional muscle strength measuring devices and relationship with lower limb muscle mass.

PARTICIPANTS AND METHODS

We included 104 healthy university students (56 male and 48 female participants) without orthopedic diseases in the lower limbs, including the knee and hip joints). We used the LCS knee extension force and Cybex (Cybex Norm CN77, CSMi Inc, Stoughton, MA, USA) knee extension torque to measure muscle strength. Meanwhile, we used the InBody (InBody 720, BioSpace Inc., Urbandale, IA, USA), a body composition meter, to measure muscle mass through the segmental bioelectrical impedance analysis (SBIA) method.

To measure knee extension force using the LCS, the participants were placed in a long sitting position on a non-resilient cot. The measurement posture was defined as an angle of 110 degrees between the thigh and trunk (70 degrees hip flexion), 30 degrees knee flexion, and an ankle joint angle in the middle position (Fig. 2).

To measure knee extension torque using the Cybex, the participants were asked to sit in a chair in the same posture as for measurement using the LCS, with their arms crossed in front of their chest (Fig. 3).

Furthermore, the force exertion mode was in isometric knee extension motion for both devices; the force was gradually raised every 5 sec without using a recoil motion. Next, the participants were instructed to maintain the full force for several seconds.

Lower limb muscle mass (lower limb muscle mass) was measured by SBIA using an InBody (InBody 720, BioSpace Inc). The right lower limb was used to measure these values in all cases.

Measurement processes are shown in Fig. 4.

Before measuring lower limb muscle strength, we attached eight electrodes, with two attached on both hands and feet. Then, we used the InBody to measure impedances of the right and left upper limbs; trunk; and right and left lower limbs by passing four types of min currents (5 kHz, 50 kHz, 250 kHz, and 500 kHz).

Fig. 1. LocomoScan (LCS).
The LCS is a compact and simple instrument for measuring knee extension force using the quad-setting method. The vertical load is measured at the green part of the mountain shape, and the quad setting training is guided by voice and display.

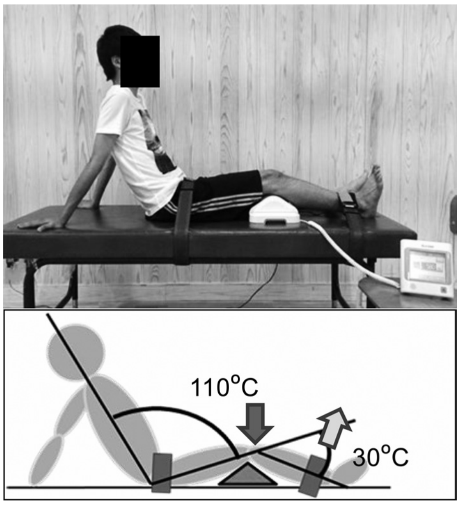
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Fig. 2. Posture for measuring knee extension force using the LocomoScan (LCS).
The participant is placed in a long sitting position on a non-resilient cot, and the measurement posture is defined as an angle of 110 degrees between the thigh and trunk (70 degrees hip flexion), 30 degrees knee flexion, and an ankle joint angle in the middle position.


[redacted]

Fig. 3 . Posture for measuring knee extension force using the Cybex.
The participant is placed in the sitting position on a chair, with the thigh and trunk at an angle of 110 degrees (hip flexion 70 degrees), knee flexion 30 degrees, and ankle joint angle in the middle position, with arms crossed in front of the chest.

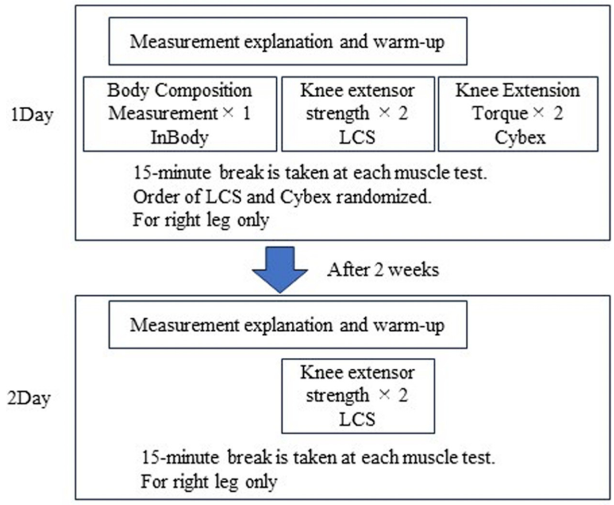

Fig. 4. Measurement flow.
LCS: LocomoScan.

During measurement, the participants performed warm-ups, we ensured that the participants knew how to properly exert force on both devices.

Measurements were performed twice by each device; the higher values were used as the measured values in the analysis. To minimize the effects of fatigue between each measurement, we allowed the participants to rest for at least 15 min; we regularly checked whether they felt fatigued. LCS was measured using the same method after 2 weeks (2Day) to verify the reproducibility of the measurement.

All measurements were taken by a single assessor to avoid inter-rater influence. To account for the influence of anthropometric effects on the measurements, comparisons were also made using the lower leg length to compensate for knee extension (LCS_1D_Max_Corr), which was the maximum knee extension force on day 1 of the LCS divided by the lower leg length.

During the analysis of results, we examined the following: 1) reproducibility of LCS measurement, 2) correlation with Cybex measurement (torque), and 3) relevance to lower limb muscle mass.

To confirm the correlation between LCS measurements, Pearson's correlation coefficient test was used to compare the initial (1Day) measurement (LCS_1D_Max) and the maximum knee extension force (LCS_2D_Max) obtained at the 2-week post-measurement (2Day). Regarding measurement reproducibility, the intraclass correlation coefficient (hereafter ICC: ICC (1, 2)) and 95% confidence interval (CI) were calculated for the first (LCS_1st), second (LCS_2nd) and maximum (LCS_Max) values on each measurement day. Using the Landis and Koch criteria, 0.41–0.60 was judged as "moderate", 0.61–0.80 as "substantial", and 0.81 and above as "almost perfect"6). For further evaluation of error quantities, the mean and standard deviation were calculated using descriptive statistics, followed by the standard error (SEM: SEM=SD√(1-ICC)), the minimum detectable change (MDC: MDC=SEM × 1.9√(2) and % MDC=100 × MDC / mean measured value) to indicate the percentage of error in relation to the measured value7). The % MDC was assessed in terms of the percentage of error in the measured values with reference to "perfect agreement" for less than 10% and "acceptable range" for more than 10–30%8).

To examine the correlation with Cybex, a single regression analysis was conducted comparing the correlation coefficient (Nm) between the knee extension torque of Cybex (Cybex_Max) and the knee extension force of the LCS (LCS_1D_Max) and the lower leg length corrected knee extension force (LCS_1D_Max_Corr).

In addition, ICCs (2, 2) and 95% CI for each measurement were calculated from LCS_1D_Max and LCS_1D_Max_Corr against Cybex_Max, as a comparison of the validity of the measurements made by the two different instruments.

Correlations between lower limb muscle mass (Muscle_Mass) and LCS_1D_Max were compared using single regression analysis. In addition, ICC (2, 2) and 95% CI were calculated using Muscle_Mass and LCS_1D_Max as a comparison between two different measurements for measurement association.

Absolute reliability between instruments was assessed by evaluating the systematic error of measurements in the comparison groups for which relative reliability was confirmed for each analyte.

If a proportional bias was determined to be present, the error would also be proportional to the true value. Therefore, the evaluation was changed to a relative axis plot (% difference plot) with the y-value relative to the x-value (mean value of the two corresponding measurements (a+b)/2), as recommended by Bland and Altman9).

SPSS (SPSS29, IBM, Tokyo, Japan) was used for statistical analysis; the significance level was set to less than 5%.

The study was approved by the Ethics Committee of our University School of Medicine (receipt numbers 978, 979, and 2020-0143). All participants provided informed consent before participating in the study. The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

RESULTS

The male participants had an average age, 20.1 ± 2.2 years (average ± SD); height, 173.9 ± 5.1 cm; weight, 67.1 ± 11.3 kg; and lower limb length, 36.9 ± 1.7 cm. In addition, the female participants had an average age, 19.5 ± 0.9 years; height, 158.7 ± 6.1 cm; weight, 53.7 ± 8.1 kg; and lower limb length, 33.8 ± 1.9 cm. Male participants had significantly greater averages compared with female ones (all, $p<0.001$) (Table 1).

Regarding the knee extension force, LCS_1D_Max was 632.2 ± 170.7 N (mean ± SD), and LCS_2D_Max was 647.14 ± 168.7 N. A significant correlation ($r=0.901$, $p<0.001$) was found between them (Fig. 5). ICC (1, 2) and 95% CI for the LCS_1st, LCS_2nd and LCS_Max values from measurements obtained on 1Day and 2Day of the LCS are presented in Table 2. The LCS_1st, LCS_2nd and LCS_Max's ICC (1, 2) were all 0.9 or higher and were "almost perfect" ($p<0.01$). The MDC and %MDC (MDC divided by the mean) of the number of LCS measurements were 110.8 N (17.9%) 120.8 N (19.4%), and 132.2 N (20.7%) for the first, second, and maximum, respectively, which were within the "acceptable range".

In terms of Cybex knee extension torque correlation, Cybex_Max was 98.0 ± 33.7N • m and LCS_1D_Max was 632.2 ± 170.7 N (mean ± SD), regression equation $y=236+4.05\times$($r=0.798$, $p<0.001$). LCS_1D_Max_Corr was 226.5 ± 70.2 N m. It significantly correlated with Cybex_Max, regression equation $y=55.12+1.75\times$($r=0.839$, $p<0.001$) (Table 3).

Table 1. Participants characteristics

	Total	Male	Female	p
	Mean (SD)	Mean (SD)	Mean (SD)	
n	104	56	48	
Age (years)	19.8 (1.8)	20.1 (2.2)	19.5 (0.9)	
Height (cm)	166.9 (9.4)	173.9 (5.1)	158.7 (6.1)	***
Weight (kg)	60.9 (11.9)	67.1 (11.3)	53.7 (8.1)	***
Lower leg length (cm)	35.5 (2.4)	36.9 (1.7)	33.8 (1.9)	***

Welch's t-test was used for statistical treatment of each item in sex differences. ***$p<0.001$.
SD: standard deviation.

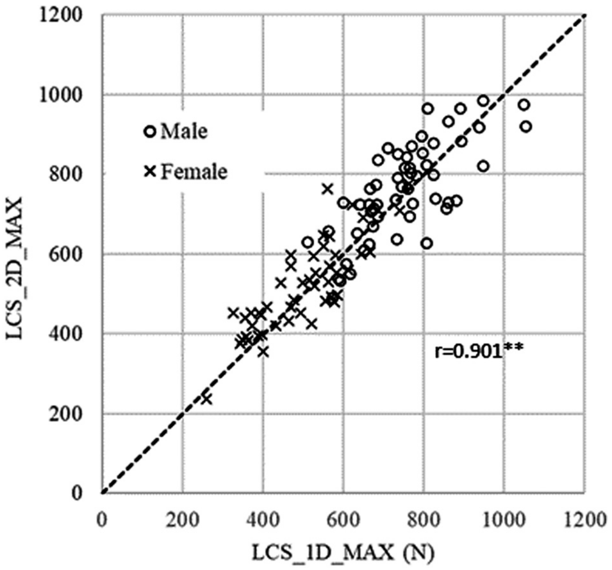

Fig. 5. Reproducibility in the first and second measurements using the LCS.
Reproducibility of the first measurement (abscissa: LCS_1D_MAX) and the second measurement (ordinate: LCS_2D_MAX) in the locomotor scan is shown.
**Pearson's correlation coefficient: $p<0.001$.
LCS: LocomoScan.

In regard to Cybex_Max, the ICC (2, 2) of LCS_1D_Max was “moderate” at 0.465 (95% CI: 0.212–0.637) and the ICC (2, 2) of LCS_1D_Max_Corr was “substantial” at 0.791 (0.692–0.859).

As for the correlation with Muscle_Mass, the right lower limb muscle mass was 7.3 ± 1.8 kg and LCS_1D_Max was 632.2 ± 170.7 N (mean ± SD), regression equation y=120+69.98 ×(r=0.747, p<0.001) (Table 3). However, for Muscle_Mass, the ICC (2, 2) for LCS_1D_Max was 0.031 (95% CI (−0.421) −0.343) without showing correlation.

The results of the Bland–Altman plot analysis for the LCS_1st, the LCS_Max values and the comparison between the LCS (LCS_1D_Max or LCS_1D_Max_Corr) and Cybex_Max are summarized in Table 4. For LCS_1st, no fixed or proportional bias was observed. For LCS_Max, although the distribution was negative with a fixed bias, no proportional bias was observed. A proportional bias was observed between LCS (LCS_1D_Max or LCS_1D_Max_Corr) and Cybex_Max. Analysis using relative axis plots confirmed that there were fixed bias and no proportional bias. For Cybex_Max, a comparison with the percent difference plot confirmed that the measurement error of the LCS ranged between 127.5 and 165.7%.

DISCUSSION

This study aimed to demonstrate the effectiveness of the LCS in clinical use in measuring knee extensor strength in the lower limb and its relationship with other instruments used, evaluating measurement reproducibility, measurement correlation with Cybex and relationship with muscle mass.

Table 2. Reliability in each LCS measurement

	ICC			Measurement error (N)		
	ICC(1,2)	95% CI	p	mean SD	SEM (%SEM)	MDC (%MDC)
LCS_1st	0.943	0.916–0.961	**	620.0 (167.4)	40.0	110.8
					6.4%	17.9%
LCS_2nd	0.934	0.902–0.955	**	622.3 (168.3)	43.6	120.8
					7.0%	19.4%
LCS_Max	0.921	0.964–0.915	**	639.6 (169.7)	47.7	132.2
					7.5%	20.7%

ICC (1,2) is used to evaluate the 1Day and 2Day reproducibility of each measurement. **p<0.01.
The mean and standard deviation of each measurement are calculated and the SEM (standard error of measurement) and MDC (minimum detectable change) are shown (95% CI).

Calculation of SEM and MDC: SEM=SD√(1−ICC), MDC=SEM × 1.9√(2)
%SEM, %MDC: The lower rows of SEM and DMC are ratios (%) divided by the average value of each measurement.
LCS: LocomoScan; ICC: intraclass correlation coefficient; CI: confidence interval.

Table 3. Comparison of relative reliability between LCS and other measurements

Comparison conditions			Mean (SD)	Regression equation		ICC		
				(r)	p	ICC (2,2)	95% CI	p
Cybex_Max	(Nm)	x	98.0 (34)					
vs LCS_1D_Max	(N)	y	632.2 (171)	y=236+4.05x (0.798)	***	0.465	0.212 to 0.637	**
vs LCS_1D_Max_Corr	(Nm)	y	226.5 (70)	y=55.12+1.75x (0.839)	***	0.791	0.692 to 0.859	**
Muscle_Mass	(kg)	x	7.3 (1.8)					
vs LCS_1D_Max	(N)	y	632.2 (171)	y=120+69.98x (0.747)	***	0.031	−0.428 to 0.343	

Cybex (Nm) vs. LCS(N) or (Nm): The knee extension torque between Cybex and LCS were compared. Single regression analysis: ***p<0.001.
Since Cybex is a torque value, the comparison is made with the correction value obtained by dividing LCS_1D_Max by the lower leg length. (LCS_1D_Max_Corr).
Lower limb muscle mass (kg) compared with LCS (N): lower limb muscle mass and LCS compared with 1Day maximum knee extension force. Single regression analysis. ***p<0.001.
I Intra-class correlation coefficient analysis is used to assess the relationship between LCS_1D_Max and Cybex and lower limb muscle mass measurements. **p<0.01.
SD: standard deviation; ICC: intraclass correlation coefficient; CI: confidence interval; LCS: LocomoScan.

Table 4. Sytematic bias for each measurement comparison

		Fixed bias			Proportional bias		LOA95	
		Mean	95% CI	p	r	p	Low	Upper
LCS_1st (1D vs. 2D)[*a]	(N)	−10.1	(−25.1 to 5.0)		0.169		−161.7	141.6
LCS_Max (1D vs. 2D)[*a]	(N)	−14.8	(−29.6 to −0.1)	*	0.058		−163.1	133.4
LCS_1D_Max vs. Cybex_Max[*b]	(%)[*c]	146.6	(144.7 to 148.5)	**	−1.134		127.5	165.7
LCS_1D_Max_Corr vs. Cybex_Max[*b]	(%)[*c]	79.5	(76.4 to 82.6)	**	−0.197		48.2	110.9

Bland–Altman analysis was used to examine systematic bias.
Additive error is indicated by the lower and upper limits of the 95% CI of the difference between the two measurements (t-test) and proportional error is indicated by the correlation between the difference between the two measurements and the mean of the two measurements (correlation coefficient “r”). *$p<0.05$, **$p<0.01$

*a: The agreement between 1Day and 2Day measurements for the first and maximum LCS was assessed (95% CI).

*b: Assessed agreement between Cybex and lower limb muscle mass measured against maximum knee extension force on day 1 of the LCS (95% CI).

*c: Percent difference plot: The measurement principles and measurements of LCS and Cybex are very different; the difference between a pair of measurements was calculated as the average of the two corresponding means (LCS_1D_Max + Cybex_Max)/2 or the relative value of (LCS_1D_Max Correction vs. Cybex_Max)/2.

CI: confidence interval; LCS: LocomoScan.

The measurement of knee extension force in the LCS was confirmed to be sufficiently reproducible. We also confirmed the relationship of knee extension force by the quad-setting method of the LCS with the values of knee extension torque on the Cybex and its correlation with lower limb muscle mass.

Reproducibility of knee extension force using the LCS was similar to the correlation coefficient of 0.92 ($p<0.01$) in male participants in the previous QTM05F study[5]. In this study, only correlation coefficients were examined. Miura et al. also pointed out that the measurement reproducibility using the LCS was ICC of (1, 1) 0.68 and that there was proportional bias in the study using Bland–Altman analysis[10]. The participants were nine young men and the results showed that the fixation method and measurement technique could affect the measurement results. Bland–Altman plot analysis confirmed fixed bias in the comparison of the maximum values in the agreement of the LCS measurements. In the comparison of the first measurement values, the measured value differences were also distributed slightly on the negative side. This may be due to the learning effect of the muscle strength measurement between Day 1 and Day 2. The difference values are small and sufficiently small compared with the LOA95.

We were able to confirm the reproducibility of the measurement of knee extension force using the quad-setting method in the LCS by conducting a study in healthy men and women (100 participants). In addition, the study showed measurement reproducibility for multiple measurements using the LCS. With sufficient explanation and warming-up, taking a single measurement is possible. Furthermore, the measurement error was found to be approximately 20% (132.2 N). These results could be used to assess actual muscle strength and changes during training.

Isokinetic dynamometers that can measure the effect of leg length on the rotational force, such as the Cybex and BioDex, are the instruments that can measure with the highest accuracy. For example, a previous study found a measurement reproducibility ranging between $r=0.89$ and 0.97 and a correlation between Cybex and Biodex (0.79 to 0.95)[11]. The correlation varies depending on the characteristics of each device, such as correction, and measurement posture[12].

Comparing measurement using the HHD and the isokinetic dynamometer, Bohannon reported an intraclass correlation coefficient (ICC) of 0.945 for duplicate measurements on the HHD and an ICC of 0.797 for comparison with the isokinetic dynamometer. They reported that HHD could be a practical alternative to the clinical measurement of muscle strength[13].

Measuring HHD by an isokinetic dynamometer is a method of measuring extension movements with the ankle part as the force point, which differs from the measurement posture and method using the LCS. In this study, the ICC was examined by including lower leg length-corrected knee extension force as a physique effect, and relative reliability was confirmed for both knee extension force and knee extension force-corrected values; fixed bias was confirmed for absolute reliability.

Knee extension force in the LCS could not be converted into knee extension torque. However, we considered that there was a relationship between the measured results.

Regarding the measurement method using the LCS, not only the quadriceps muscle, but also the hip extension movement is considered to influence the measured values. Furthermore, due to the lack of a backrest and the influence of the upper body to maintain the measurement posture, the measured values are considered to include the force due to hip extension torque (e.g. hamstring contraction) in addition to knee extension torque. To further improve the correlation between the measurement methods of different devices[11], matching leg positions and body fixation methods between measurement devices is also necessary.

However, Isokinetic dynamometers, despite being highly accurate, are large and heavy, making them difficult to carry to the measurement site and placing a heavy burden on older adults and patients for measurement. Problems have been identified with HHDs, such as insufficient fixation capacity at sites including the knee, where forces are high, fixation conditions during measurement, and standardization of the examiner's technique14).

Therefore, knee extension force using the LCS is considered to correlate with knee joint torque using the Cybex. It is also portable during measurement and is considered to be a practical alternative for clinical muscle strength measurement. However, caution should be exercised in comparing the values with those of Isokinetic dynamometers.

Moreover, examining the correlation between the LCS knee extension force and the muscle mass of the entire right lower limb revealed a significant correlation with r=0.747 for the LCS knee extension force. However, intraclass correlation analysis showed no agreement with an ICC (2, 2) of 0.031. We suggest that these results indicate that muscle mass could be related to muscle strength, but that muscle mass cannot be used to estimate muscle strength.

Muscle mass is included in the diagnostic criteria for sarcopenia2). However, changes in muscle mass and strength vary with age, as reported by Wiegmann et al15). The European Consensus on the Definition and Diagnosis of Sarcopenia2) states that in muscle strength assessment techniques, grip strength is measured for simplicity, whereas lower limb muscle strength is significantly related to gait and physical function. Senda et al. reported that lower limb muscle strength was significantly reduced, even though grip strength was maintained16).

The results found here are in younger people; future verification of muscle mass and strength is considered necessary to focus on older people.

We suggest that the LCS can be used to measure knee extensor muscle strength as an alternative to commonly used measures such as grip strength, as the largest muscle in the body is the quadriceps.

Quadriceps muscle strength is related to squat motion17), walking speed18), and standing up19), and these motions have been reported to be effective in training for activities of daily living. Hence, we suggest that it is a quantitative parameter to evaluate the therapeutic effect. However, the commonly used measuring devices have field limitations, and quantitative analysis of preventive, long-term care for muscle strength in older adults remains lacking.

In this study, the LCS was found to be portable and could enable easy and reproducible measurement of lower limb muscle strength, facilitating the introduction of new evaluation indices in rehabilitation, on-site, clinical and health check-ups, where measurement has been difficult due to problems with equipment portability, measurement accuracy, and differences in examiners' skills.

We have previously used this device to study age-related changes in lower limb muscle strength in healthy participants20); its association with the development of knee osteoarthritis21) and the effects of lower limb muscle strength on the body.

The present study only confirms the reproducibility of knee extension force and its relationship with other measurements in healthy university students using the LCS. Analyzing the measurement locations with knee joint torque using the Cybex and other systems is also difficult. However, we suggest that we have confirmed the validity of using the LCS for measurement.

Whether similar results could be obtained in older adults remains unclear. We also suggest that cross-sectional and longitudinal studies of the relationship with muscle mass should also be conducted in the future.

Furthermore, we suggest that in actual practice, quadriceps muscle strength can be used to assess measurability and efficiency as a measure of knee extension strength mainly in older adults and patients. However, examining the relationship between knee extension strength and disease and activities of daily living and assessing the relationship between muscle mass and muscle strength are necessary.

In conclusion, we have improved and developed a simple lower limb muscle strength measuring device with adequate measurement reproducibility, confirmed the relationship of the measured values with a multifunction dynamometer, and correlated them with lower limb muscle mass. The LCS is a commercially available measuring instrument. This study is the first to clarify the measurement validity of that instrument. We suggest that it can be used as an assessment indicator by enabling simple measurement in medical practice.

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Conflict of interest

The authors received and will not receive any benefits or funding from any commercial party related directly or indirectly to the subject of this article.

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