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Development of sarcopenia assessment system using balance and gait ability: Preliminary tests in the elderly

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Abstract.
BACKGROUND: Sarcopenia is a disease that has recently become an issue, and research on various assessment methods is being conducted based on guidelines published for the diagnosis of sarcopenia. However, most assessments are complex because the inspector must measure each device to collect data, or the elderly must directly manipulate and get assessment.
OBJECTIVE: In this study, we developed an sarcopenia assessment system to assess and analyze various sarcopenia in one system.
METHODS: The system consists of a scaffold sensor for balance ability assessment, a chair sensor for assessing the walking and lower extremity function, and a hand-held dynamometer for assessing grip strength. The balance pad consists of 326 FSR (Force Sensitive Resistor) sensors, and the accuracy is 10 kg/$\pm$ 10%. The chair sensor applied four weight sensors (Loadcells) to the corner of the hip of the chair, and the accuracy is up to 150 kg $\pm$ 10%, and the resolution is 1 kg $\pm$ 10%. All data is transmitted to the software through a USB cable to assess sarcopenia through data analysis. The software has built a database to manage user-specific data. The assessment items consisted of “Short Physical Performance Battery (SPPB) Test” and “Hand Grip Strength Test.” After completion, the software automatically terminates the assessment results and classifies sarcopenia according to the presented reference value.
RESULTS: The average value of the total SPPB test scores, including the balance test, gait speed test, and chair stand test, of all participants was 9.06 $\pm$ 1.97. The average values of the balance test, gait speed test, and chair stand test scores of all participants were 8.48 $\pm$ 2.80 sec (score 3.28 $\pm$ 1.23), 1.05 $\pm$ 0.26 m/sec (score 3.69 $\pm$ 0.79), and 16.05 $\pm$ 4.62 sec (score 2.08 $\pm$ 1.13). The average value of the hand grip test of all participants was 28.57 $\pm$ 2.94 kgf.
CONCLUSIONS: A preliminary assessment was conducted on the elderly in their 60 s or older with the developed system, and its performance confirmed that the assessment and result analysis were conducted well without any errors in software or

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hardware. Future studies intend to verify the reliability and accuracy of the assessment results compared to the existing direct measurement methods. In addition, we would like to conduct a study to establish data on the muscle reduction index by age group of Koreans.

Keywords: Sarcopenia, assessment system, preliminary test, rehabilitation, healthcare

1. Introduction

Sarcopenia is a disease in which muscle mass decreases with aging and physical function such as muscle strength, and walking speed decreases. Sarcopenia was classified as a disease in 2021 after the United States and Japan. Sarcopenia is a disease that can lead to hospitalization and death by increasing the risk of falls and fractures due to decreased daily life function caused by decreased physical activity ability [1,2]. Currently, as many countries enter an aging society, the elderly population and the average age of survival are increasing. Therefore, active research and efforts are needed to prevent and manage Sarcopenia. Recently, various studies have been conducted to assess sarcopenia.

In 2010, the European Working Group on Sarcopenia in Older People (EWGSOP) developed a sarcopenia diagnostic algorithm. It was challenging to apply this algorithm to Asians because they, including Koreans, generally have smaller bodies and more body fat and activity than Westerners [3]. Since then, the Asian Working Group on Sarcopenia (AWGS) has been formed, and they published new guidelines for diagnosing patients with sarcopenia that can be used in local society or hospitals in 2019 [4]. In the assessment of sarcopenia, various musculoskeletal function assessments are performed using muscle mass estimation of the limbs (arms and legs), muscle strength estimation, and physical function assessment [5]. In addition, Yun et al. (2022) developed a deep-learning algorithm for diagnosing sarcopenia using a mobile device [6]. Lee (2020) proposed using ultrasound to assess sarcopenia by analyzing muscle thickness, Fascicle length, Pennation angle, Echo intensity, and Cross-sectional area [7]. Teixeira (2022) developed a mobile monitoring system for diagnosing and screening sarcopenia by linking Hand grip and Lipowise (subcutaneous fat meter) based on EWGSOP2 [8].

Most studies on the assessment of sarcopenia are conducting DXA, measurement of limb muscle mass using Multi-frequency bioelectrical impedance analysis (MF-BIA), Gait speed test, chair stand test, hand grip strength test, and then analyzing the results. These assessments have the inconvenience of requiring the tester to perform measurements on each device, collect the data from each device, and analyze data. The method using such a mobile device has the advantage of being easy to assess, but it is difficult for the elderly to perform it directly. In addition, despite the various inconveniences and problems of the existing method, research on developing a system that integrates, assesses, and analyze in one system is insignificant. Therefore, this study aims to develop a sarcopenia and functional assessment system for sarcopenia assessment.

2. System configuration

2.1. Configuration of hardware

Figure 1 is the hardware configuration of the sarcopenia assessment system developed in this study. It consists of a scaffold sensor for evaluating balance ability, a chair sensor for evaluating lower extremity function, and a grip dynamometer for measuring the strength of grip. The balance pad was manufactured in a size of 660 mm(L) $\times$ 520 mm(W) $\times$ 10 mm(H), which is developed for the detection of foot position.

Fig. 1. The hardware configuration of sarcopenia assessment system.

326 FSR sensors were used, and the sensor's accuracy was 10 kg/ ± 10%. In addition, blue and red LEDs were used to show the position of the soles of the feet when evaluating according to three conditions (two-legged standing, half-row standing, and standing in line). The balance assessment measures the amount of body agitation for 10 seconds under three conditions.

The chair sensor for measuring walking and lower limb function was manufactured in a size of 430(L) $\times$ 500(W) $\times$ 750 $\sim$ 840(H) mm. A four-stage height adjustment device was applied at 20 mm, 40 mm, 60 mm, and 80 mm based on the floor surface to adjust the height of the chair according to the physical conditions of the subject. Four weight sensors (Loadcells) were applied to the corner of the hip of the chair, and the accuracy of the sensor was up to 150 kg ± 10%, and the sensor resolution was 1 kg ± 10%. The weight sensors count the number of stand-up-and-sit-back actions from the chair sensor by detecting subjects' weight to assess the lower extremity muscle function. A distance measuring sensor (LiDAR Sensor) is applied to the chair sensor's backrest to measure the subject's walking speed and time in a specific section (90 cm to 700 cm). The distance sensor's measurable distance is up to 7 m ± 10%, and its resolution is 1 cm ± 10%.

TAKEI hand grip dynamometer was used to measure the strength of grip force, to which a weight sensor (Loadcell) was applied. The measurement range is 5 to 100 kgf ± 2 kgf, and the resolution is 0.1 kgf. The grip force was measured three times with the right hand and three times with the left hand. All data is transmitted to the software through a USB cable, which automatically analyzes the data to assess for congruence with the range of sarcopenia.

2.2. *Configuration of software*

Figure 2 is the software of the sarcopenia assessment system developed in this study. A database was established to manage data for each user. The SPPB test assesses the degree of muscle loss by scoring a "Balance Test (4 points)", "Gait Speed Test (4 points)", and "Chair Stand Test (4 points)." The balance test consists of a "Side-by-side Stand," "Semi-tandem Stand," and "Tandem Stand."

In the balance test, if the subjects hold their balance for 10 seconds in a side-by-side and semi-tandem stand, they will each get one point. If the subjects hold a tandem stand for 10 seconds, they will get 2 points. If they hold between 3 to 9.99 seconds, they will get 1 point, and those under 3 seconds will get 0 points. The risk of posture control is assessed according to the sum of the scores, and it is classified as

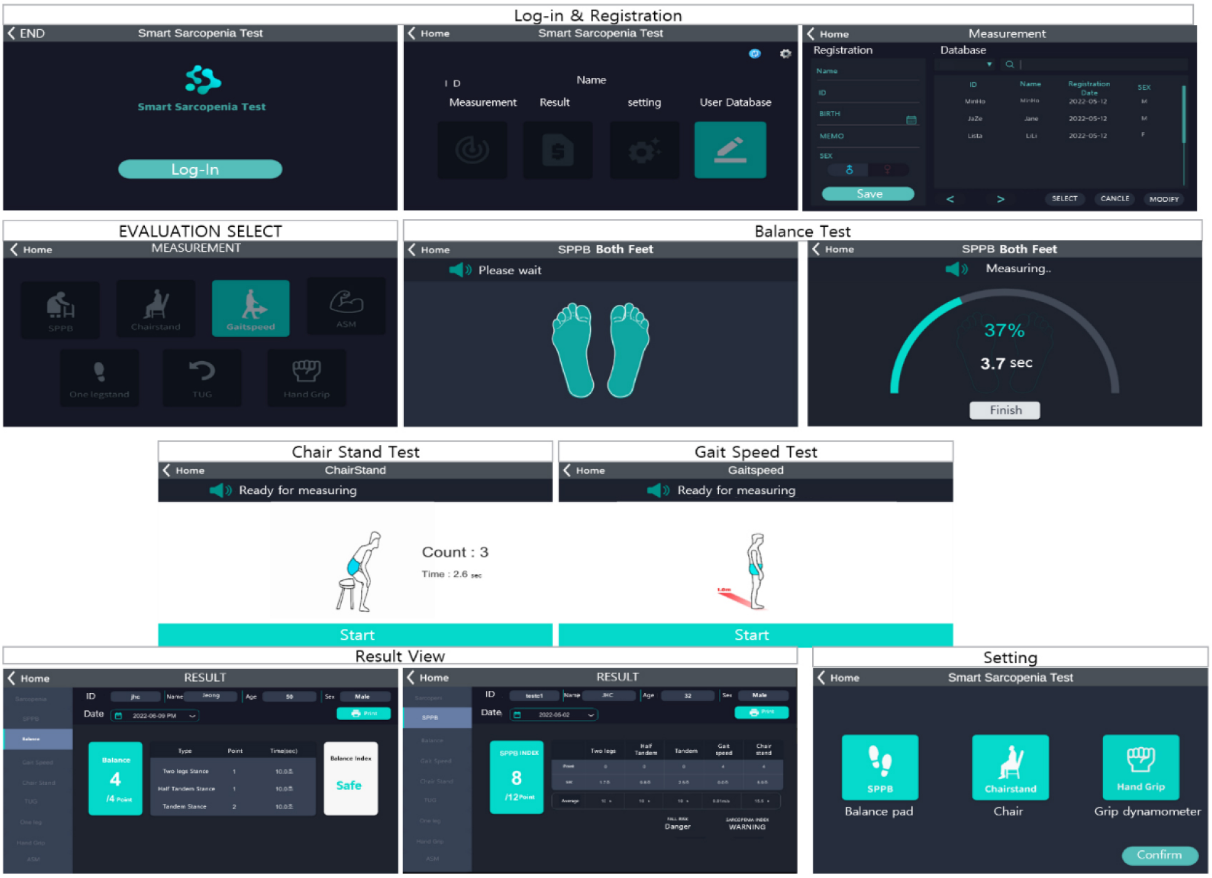

Fig. 2. The software of sarcopenia assessment system.

"Good" if the score is 4 points, "Caution" if the score is 3 points, and "Warning" if the score is 2 points or less. The Gait speed test measures the time the subject walks a 4-meter course straight to the front of the chair sensor at their usual speed. Subjects score 4 points if their average speed is 0.83 m/sec or more, 3 points for 0.83 $\sim$ 0.65 m/sec, 2 points for 0.64 $\sim$ 0.46 m/sec, 1 point for less than 0.46 m/sec, and 0 points for do not attempt.

The chair stand test starts with the subject sitting on the chair sensor and repeating the stand-up from a chair without using their arms five times. Subjects score 4 points if the total time is less than 11.19 seconds, 3 points for 11.20 to 13.69 seconds, 2 points for 13.70 to 16.69 seconds, 1 point for 16.70 to 59.99 seconds, and 0 points for subjects who do not attempt or more than took 60 seconds. The SPPB test results are assessed according to the total score, and if the total score is 10 or more, it is classified as "Good," if the total score is 9 to 3, it is classified as "Caution," and if the score is 2 or less, it is classified as "Warning."

For the hand grip strength test, which is an additional function, hold the grip dynamometer and measure the right and left hands alternately three times for three seconds. If the average value is 28 kgf or more for men and 18 kgf or more for women, it is classified as 1 point, otherwise 0 point. These assessment results are stored or printed in reports and can be classified by date to observe the change. The SPPB test criteria applied in this study were developed based on the SPPB criterion table proposed by the National

Table 1
Characteristics of the participants

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/^{2})
60 s Average (SD) ($n = 13$)	65.77 ($\pm$ 2.77)	161.77 ($\pm$ 9.74)	65.58 ($\pm$ 12.07)	24.89 ($\pm$ 2.49)
70 s Average (SD) ($n = 13$)	74.92 ($\pm$ 2.60)	161.15 ($\pm$ 9.94)	64.81 ($\pm$ 8.55)	24.98 ($\pm$ 2.74)
80 s Average (SD) ($n = 10$)	81.70 ($\pm$ 0.95)	160.20 ($\pm$ 7.60)	60.21 ($\pm$ 5.25)	23.48 ($\pm$ 1.68)

Institute of Aging (NIA) in the United States and the Korean Geriatrics Society's assessment index of sarcopenia [9,10].

3. Methods

A preliminary test was conducted to verify the hardware and software performance of the Sarcopenia assessment system developed in this study. The participants were 36 senior citizens in Gwangju Metropolitan City, aged 60 years and over, with no medical history of the musculoskeletal or nervous system in the past 6 months (men, $n = 17$, women, $n = 19$, age, 73 $\pm$ 6.69 years, weight, 63.8 $\pm$ 9.34 kg, height 161 $\pm$ 9.04 cm) (Table 1). In addition, the purpose and risks of this study were fully explained to the participants; the participants signed a consent form for the use of the test results data only for this study. All participants performed SPPB tests and hand grip strength tests using the developed device. In addition, measurement data were divided into age groups (60 s, 70 s, and 80 s).

4. Result

Table 2 shows the results of sarcopenia evaluation of subjects in their 60 s, 70 s, and 80 s using sarcopenia assessment system. The average value of the total SPPB test scores of all participants was 9.06 $\pm$ 1.97, and by age group, it was 9.54 $\pm$ 2.47 in the 60 s, 8.15 $\pm$ 1.46 in the 70 s, and 9.60 $\pm$ 1.51 in the 80 s.

The average value of the balance test scores of all participants was 8.48 $\pm$ 2.80 sec (score 3.28 $\pm$ 1.23), and by age group, it was 7.86 $\pm$ 4.10 sec (score 3.08 $\pm$ 1.75) in the 60 s, 8.60 $\pm$ 2.04 sec (score 3.23 $\pm$ 1.01) in the 70 s, and 9.12 $\pm$ 1.21 sec (score 3.60 $\pm$ 0.52) in the 80 s.

The average value of the Gait speed test scores of all participants was 1.05 $\pm$ 0.26 m/sec (score 3.69 $\pm$ 0.79), and by age group, it was 1.17 $\pm$ 0.30 m/sec (score 3.77 $\pm$ 0.83) in the 60 s, 3.54 $\pm$ 0.97m/sec (score 3.54 $\pm$ 0.97) in the 70 s, and 1.03 $\pm$ 0.19 m/sec (score 3.80 $\pm$ 0.42) in the 80 s.

The average value of the chair stand test scores of all participants was 16.05 $\pm$ 4.62 sec (score 2.08 $\pm$ 1.13), and by age group, it was 14.17 $\pm$ 4.84 sec (score 2.69 $\pm$ 1.25) in the 60 s, 18.36 $\pm$ 3.80 sec (score 1.38 $\pm$ 0.77) in the 70 s, and 15.50 $\pm$ 4.39 sec (score 2.20 $\pm$ 0.92) in the 80 s.

Table 3 shows the average value of hand grip test of all participants was 28.57 $\pm$ 2.94 kgf, and by age group, it was 28.97 $\pm$ 3.12 kgf in the 60 s, 26.45 $\pm$ 2.70 kgf in the 70 s, 30.88 $\pm$ 2.85 kgf in the 80 s.

5. Discussion

Recently, research for the assessment of sarcopenia has been conducted in various fields, such as engineering and medicine. However, research on the development of devices for the assessment of sarcopenia is insignificant. In addition, the method using mobile devices developed in previous studies

Table 2
Result of sarcopenia assessment system

	SPPB test				
	Subject No. (SEX)	Balance (sec) /score	Gait speed (m/s) /score	Chair stand (sec) /score	SPPB score (Total: 12)
60 s ($n = 13$)	60_A(M)	10/4	1.2/4	14/2	10
	60_B(M)	0/0	1.6/4	16.5/1	5
	60_C(M)	10/4	0.4/1	14.3/3	8
	60_D(M)	10/4	1.2/4	15.6/2	10
	60_E(M)	2.2/0	1.1/4	26.5/1	5
	60_F(F)	10/4	1.2/4	10.7/4	12
	60_G(F)	10/4	1.2/4	15.4/2	10
	60_H(F)	10/4	1.2/4	14.4/4	12
	60_I(F)	10/4	1.6/4	9.6/4	12
	60_J(F)	10/4	0.9/4	17.1/1	9
	60_K(F)	10/4	1.3/4	9.9/4	12
	60_L(F)	0/0	1.06/4	6.43/4	8
	60_M(F)	10/4	1.2/4	13.8/3	11
70 s ($n = 13$)	70_A(M)	10/4	0.9/2	12.4/3	9
	70_B (M)	10/4	1.0/4	17/1	9
	70_C (M)	7.8/3	1.1/4	17.4/1	8
	70_D (M)	7.1/2	1.1/4	18.1/1	7
	70_E (M)	10/4	0.3/1	18.6/1	6
	70_F (M)	10/4	1.1/4	23.9/1	9
	70_G (M)	10/4	1.1/4	21.5/1	9
	70_H (F)	10/4	1.0/4	16.3/2	10
	70_I (F)	7.1/3	1.1/4	17.5/1	8
	70_J(F)	9.7/3	1.0/4	11.9/3	10
	70_K(F)	10/4	0.9/4	17.7/1	9
	70_L(F)	6.6/2	0.8/3	23.6/1	6
	70_M(F)	3.5/1	0.9/4	22.8/1	6
80 s ($n = 10$)	80_A(M)	10/4	1.0/4	14.7/2	10
	80_B(M)	8.4/3	1.2/4	14.4/2	9
	80_C(M)	10/4	0.8/3	15.3/2	9
	80_D(M)	7.3/3	0.8/3	26.6/1	7
	80_E(M)	8.4/3	1.2/4	14.4/2	9
	80_F(F)	7.1/3	1.0/4	18.1/1	8
	80_G(F)	10/4	1.0/4	15.3/2	10
	80_H(F)	10/4	0.9/4	13.3/3	11
	80_I(F)	10/4	1.0/4	12.6/3	11
	80_J(F)	10/4	1.4/4	10.3/4	12

Table 3
Result of handgrip strength test

	60 s ($n = 13$)	70 s ($n = 13$)	80 s ($n = 10$)
Hand grip strength (kgf)	28.97 ± 3.12	26.45 ± 2.70	30.88 ± 2.85

has the advantage of being easy to assess. However, it is difficult for the elderly to collect accurate data or perform it themselves. Therefore, this study attempted to develop Sarcopenia assessment system for assessing sarcopenia and the lower extremity function. A chair-type device that assesses walking and lower extremity functions using Loadcell and LiDAR sensors was developed, and a balance board for balance assessment was developed using FSR sensors.

Grip dynamometer uses commercially available tools, and all hardware can be linked to software through a USB cable, allowing data to be automatically collected and analyzed. In order to verify the performance of the developed device, a preliminary test was conducted on 36 elderly people aged 60 or older. In the preliminary test, the SPPB test and hand grip strength test were performed, and as a result, digitized data by age group could be collected. In the case of the SPPB test, it was confirmed that the average value of the total score decreased as the age group increased, and the Gait speed test, one of the SPPB tests, showed that the walking speed decreased with age group.

These results were consistent with the findings of Kim et al. (2012) and Cho et al. (2019) that the prevalence of sarcopenia increases with age [11,12]. Insufficient nutrition and muscle failure to adapt to nutrition, such as essential amino acids, is one of the causes of sarcopenia [13]. In old age, it was observed that sarcopenia intensifies due to a lack of skeletal muscle accumulation and a decrease in skeletal muscle as age increases [14]. A decrease in skeletal muscle mass due to aging leads to decreased physical activities such as balance ability and walking function and a decrease in daily life performance [15]. During the SPPB test, there were no peculiarities in the results of the chair stand test and the balance test. The hand grip strength test also found no peculiarities in their result. Due to the characteristics of the elderly, it is believed that the measurement environment on the day of evaluation and the subjects' psychological and physical conditions affected the test's performance.

There was no difficulty using the equipment developed in this study to assess the sarcopenia of the elderly by experts in related fields. It was also confirmed that collecting quantitative assessment data and analyzing the results were performed without problems. However, in the case of balance boards, there was a problem that the sensor's sensitivity was too high that the Semi-tandem stand posture and the Tandem Stand posture were not adequately recognized, except for the side-by-side stand posture of the elderly with reduced balance ability. Sometimes, assessment was impossible for the elderly who weighed too little. In order to compensate for these problems, a function capable of adjusting sensor sensitivity should be added. In addition, there was no separate safety device to prevent the subject from falling, so the risk of falling was expected. When measuring using a balance board, it is judged that a handle or an auxiliary device for safety is required on the left and right sides or in front.

In the case of chair sensors, when performing the Gait speed test, there were cases where it could not be measured if it deviated from the left and right recognition range of the LiDAR sensor, and it could cause problems when performing the test of the elderly who could not walk in a straight line. In order to compensate for these limitations, the assessment is expected to be carried out accurately only when the software shows a pop-up of route departure information and marks the floor of the space to be inspected using tape. Through the results of this study, it was possible to confirm the muscle loss index, walking speed, and balance point of the elderly by age group on various scales. It was confirmed that as the age group increased, the muscle loss index and walking speed tended to decrease. In future studies, it is necessary to identify characteristics according to changes in physical function such as muscle loss index, Gait speed, chair stand, and balance by age group, and to study the composition of customized exercise guides to prevent and recover sarcopenia.

6. Conclusions

In this study, a chair sensor and a balance board were developed to assess sarcopenia and lower extremity function, and data measured with the equipment and grip dynamometer were automatically linked and analyzed in software. As a result, a system that can quickly check the overall measurement results and whether sarcopenia is applicable was developed. Next, through a preliminary test of the elderly, it was confirmed that hardware and software were well assessed and analyzed without errors. However, there is a limitation in that the accuracy and reliability of the product developed in this study needed to be verified compared to the existing direct assessment method. Future studies should verify the reliability and accuracy of the evaluation results compared to the existing direct assessment methods. In addition, we would like to conduct a study on the characteristics of Koreans' muscle loss index data by age group.

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Conflict of interest

None to report.

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