A novel method of frailty identification for elderly people by Sit-to-Stand-5 test

Takumi Nunokawa[1], Zhongwei Jiang[1], Minoru Morita[1], Keiko Doi[2], Tsunahiko Hirano[2], Kazuto Matsunaga[2]
[1]Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Japan
[2]Graduate School of Medicine, Yamaguchi University, Japan
jiang@yamaguchi-u.ac.jp

Abstract: The Sit-to-Stand-5 test (SS-5 test) is often used clinically as a simple method for evaluating lower limb function. The total time of 5 times sit-to-stand is the parameter to assess the lower limb function. In this study, whether the SS-5 test can be applied for identification of frailty was investigated. Outpatient respiratory patients, 8 healthy, 10 prefrailty and 3 frailty subjects who were identified by the J-CHS criteria, underwent the SS-5 test using a floor reaction forces meter. The total time *T*, the time *T1* from trunk forward lean to standing position, and the time *T2* from hip lift to standing position were measured. Two cases, healthy group vs. non-healthy group (Prefrailty + frailty) and the frailty group vs. non-frailty group (healthy + prefrailty), were verified. The results showed that the total time *T* is not suitable for distinguishing in both cases but the time *T1* and *T2* have high potential to identify frailty group from non-frailty group. Especially the time *T1* shows the high AUC of 0.94 and it gives high performance at the optimal cutoff value of 0.53. The test results are the specificity of *T1* (the percentage of people who test as non-frailty among those who are not frailty) is 0.99, PPV=0.92 and NPV=0.94.

Key-Words: *Sit-to-Stand, SS-5 test, Frailty identification, Floor reaction force*

1. Introduction

Muscle mass decreases with age, especially in the lower limbs [1]. The lower limbs are involved in mobility functions, and as these functions decline, activities of daily living are limited, leading to frailty and the need for nursing care. Assessment and prevention of functional decline in the lower limbs are important for extending healthy life expectancy. Sit-to-Stand-5 test (SS-5 test) is one of the methods to evaluate lower limb function for the elderly. The SS-5 test determines functional decline by measuring the total time (*T*) required to stand up and sit down 5 times as fast as possible. This test is often used in facilities for the elderly because it is simple and can be performed using only a chair and a stopwatch. The SS-5 test is an effective method of assessing physical function because the movement of sit-to-stand is related to knee extension and knee flexion muscle strength and decline in activities of daily living (ADL) [2][3].

Regarding the relationship between the SS-5 test and frailty, the Study of Osteoporotic Fracture (SOF) index proposed "the inability to rise from a chair 5 times without using their arms" as one of the diagnostic items for frailty [4]. In our clinical study, it is found that the frailty elderly people, who were judged by the Japanese version of the Cardiovascular Health Study criteria (J-CHS criteria), which is often used as a screening index for frailty, are often able to sit down and stand up continuously. However, standing-up and sitting-down at the maximum effort speed may cause muscle and joint damage, and may be difficult for frailty elderly people to

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*Corresponding author: Zhongwei Jiang
E-mail address: jiang@yamaguchi-u.ac.jp

complete. Therefore, the SS-5 test at "ordinary speed," in which the elderly person stands and sits at his/her own pace is adapted in this study. The purpose of this study is to investigate whether the SS-5 test at ordinary speed is able to discriminate frailty and to explore the efficient evaluation parameters. Currently the total time is the only evaluation parameter in SS-5 test. However, if SS-5 test performs at "ordinary speed", the total time might lose its effectiveness. In this study a balance board is introduced to SS-5 test, the total time and the time intervals related to the floor reaction force are measured to explore new evaluation parameters for identification of frailty.

2. Measurement method

2.1 Subjects

A total of 21 elderly patients (15 males and 6 females) who attended Yamaguchi University Hospital were subjects of the experiment. Their ages were 71.0±8.7 years, heights were 163.5±7.3 cm, and weights were 63.2 ± 10.4 kg. The purpose and method of the experiment were fully explained to the subjects, and their consent was obtained. This study was conducted after obtaining approval from the Ethical Review Board of Medical Research of Yamaguchi University Hospital (approval number: H2021-031).

2.2 Measurement item

2.2.1 SS-5 test

The SS-5 test was conducted at "ordinary speed". Figure 1 shows the measuring system of SS-5 test. The subject was seated shallowly on a 40-cm-high chair, with both legs on the floor reaction force meter, shoulder-width apart, and arms crossed in front of the chest at all times. The subject performed 5 standing and sitting movements continuously at their own pace without using their arms. When standing, the subject was instructed to extend the knee joint and hip joint to the maximum extent. After 1 or 2 times practice, the floor reaction force was measured from the start of the movement to the completion of 5 standing up and sitting down.

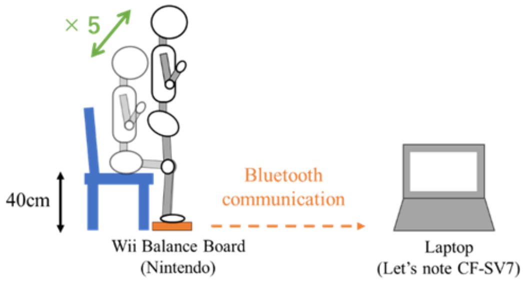

Fig. 1 Measuring system of SS-5 test.

In this experiment, a Wii balance board (Nintendo) was used for measuring the floor reaction force. This device has four load sensors in each corner and to measure the vertical floor reaction forces during standing and sitting. The Wii Balance Board was connected to a PC (Let's note CF-SV7) via Bluetooth and the data is recorded at a sampling frequency of about 100 Hz.

2.2.2 J-CHS criteria

The subjects were first diagnosed by the J-CHS criteria. The J-CHS criteria consists of five items: (1) Weight Loss, (2) Decrease in daily Activities, (3) Subjective feeling of Fatigue, (4) Decreased muscle strength (Grip Strength), (5) Decreased physical ability (Gait Speed). 3 or more of the 5 items is classified as frailty, 1 or 2 of 5 items is classified as prefrailty, and 0 items is considered healthy [5]. Grip strength was measured twice with the left and right arms, with the maximum value as the respective grip strength and the average value of the left and right arms as the measured grip strength. Walking speed was measured by performing a 5-meter walking test. In this study, non-healthy were defined as prefrailty and frailty, and non-frailty were defined as healthy and prefrailty.

3. Identification of frailty by total time

All subjects, including frailty subjects, were able to complete the SS-5 test. Figure 2 shows two typical floor reaction force waveforms during the SS-5 test for healthy and frailty elderly subjects. The floor reaction force

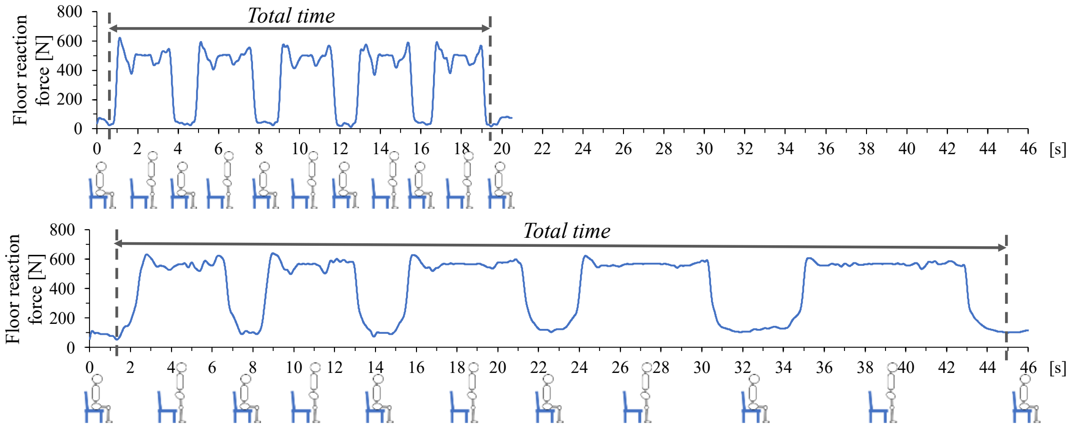

Fig. 2 Floor reaction force waveforms of SS-5 test (upper: a healthy subject, lower: a frailty subject)

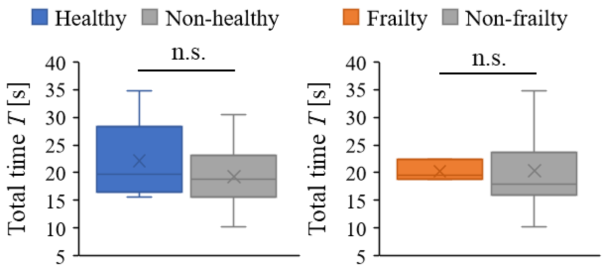

Fig. 3 Boxplot of Total time (*T*) in two cases

waveforms were smoothed by applying the FIR low-pass filter (cutoff frequency of 4 Hz). According to Figure 2, the floor reaction force increases during the standing up motion and decreases during the sitting down motion, indicating a variation of 5 standing/sitting cycles. Therefore, it is possible to calculate the time required for 5 standing and sitting movements (Total time) using the floor reaction force. The start and end of the test were set as the time when the floor reaction force was at its minimum at the 1st standing and the 5th sitting, respectively.

Figure 3 shows a comparison of Total time (*T*) measurements in healthy vs. non-healthy and frailty vs. non-frailty groups. The healthy group was 8 (38%), the non-healthy group was 13 (62%), the frailty group was 3 (14%), and the non-frailty group was 18 (86%). The Mann-Whitney U test showed no significant difference between both the healthy vs. non-healthy group and the frailty vs. non-frailty group ($p > 0.05$). Therefore, it is difficult to discriminate frailty by total time (*T*).

4. New Parameter exploration

4.1 New evaluation parameters

When a person stands up from a chair, the suture muscles and rectus femoris muscles use the forward propulsive force generated by tilting the trunk forward to lift the buttocks off the seat. The lower limb muscles (e.g., gluteus maximus, vastus medialis, hamstring) then push the body elevated [6]. Therefore, it is thought that a large amount of muscle power is exerted during the time when the body load is applied to the lower limbs, in other words, from anterior trunk tilt to standing, and from buttock release to standing. Therefore, the time of body movement during these periods has a large impact on lower limb muscle strength.

The floor reaction force and the rate of force development (RFD) during standing movement is shown in Figure 4. In the sitting position, both legs are placed on the floor reaction force meter, so the floor reaction force value is constant (point a). In the initial phase of the standing up motion, the trunk tilts forward and the floor reaction force decreases (point b). After the forward leaning motion is completed, the hips leave the chair, the knee joints, ankle joints and hip joints are extended, and the floor reaction force increases as the body is pushed up to a higher position. RFD reaches its maximum at the time when the buttocks leave the chair (point c). The

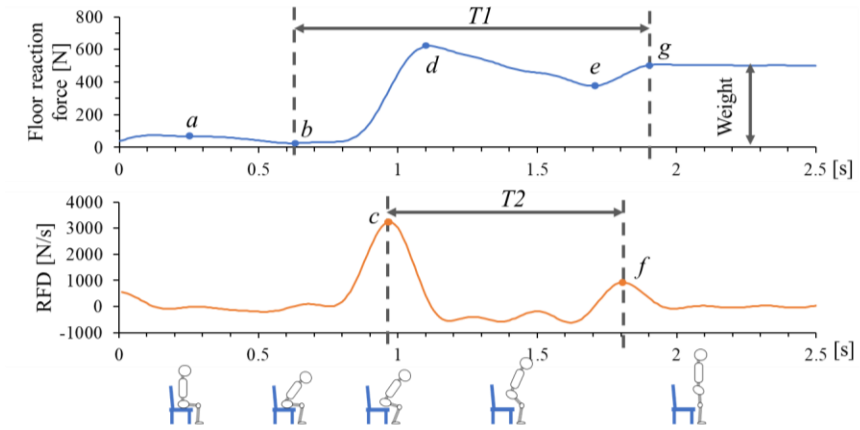

Fig. 4 Definition of each parameter (upper: floor reaction force, lower: rate of force development (RFD))

floor reaction force is at its maximum when the acceleration during body elevation is at its maximum (point d). The floor reaction force then decreases with knee extension (point e), and in the upright position, the floor reaction force is equal to the body weight value (point g). The above points are extracted automatically by a peak detect algorithm. Based on the above explanation, two parameters are considered in this study.

(1) Stand-up movement time (*T1*)

This parameter corresponds to the time from anterior trunk tilt to the standing position. The time is taken from the time when the floor reaction force is at its minimum (point b) to the time when the floor reaction force is equal to the body weight value (point g). The time is calculated in units of 10 ms. Since each SS-5 test has 5 cycles there are 5 samples of *T1*. In order to increase the samples, 5 *T1*s plus its average, total of 6 samples of *T1* are taken into account in each SS-5 test.

(2) Body elevation time (*T2*)

This parameter corresponds to the time from buttock release to the standing position. It is the time from the maximum RFD (point c) during the interval of increasing floor reaction force (between point b and d) to the peak RFD (point f) during the interval of increasing floor reaction force and returning to the body weight value (between point e and g). The time is calculated in units of 10 ms. The number of samples obtained is the same as *T1*.

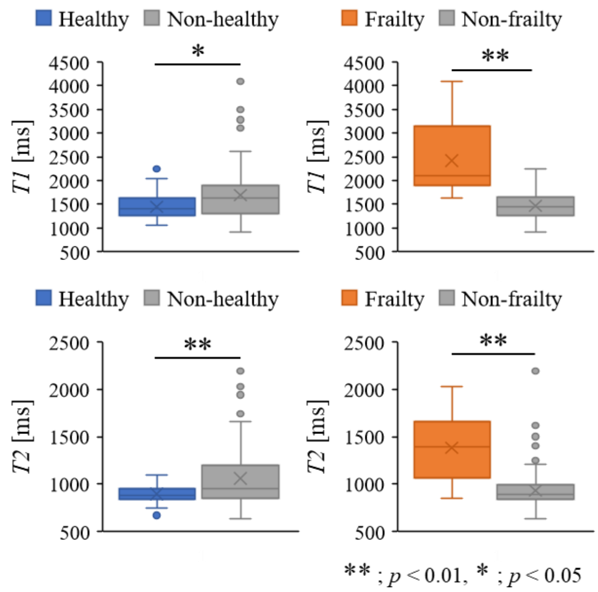

Fig. 5 Comparison of measurements for each time parameter

Figure 5 shows boxplots corresponding to *T1* and *T2* between the case in healthy vs. non-healthy and the case in frailty vs. non-frailty groups. The number of samples in each group is as follows. The healthy group was 48 (38%), the non-healthy group was 78 (62%), the frailty group was 18 (14%), and the non-frailty group was 108 (86%). Mann-Whitney U test showed that there were significant differences in both *T1* ($p < 0.05$) and *T2* ($p < 0.01$) between the healthy vs. non-healthy groups. There were also significant differences in *T1* ($p < 0.01$) and *T2* ($p < 0.01$) between the frailty and non-frailty groups.

4.2 Verification of frailty identification

First, logistic regression was performed on the measurements of *T1* and *T2*, which were classified as healthy vs. non-healthy and frailty vs. non-frailty, to calculate the predictive probability. From the binomial logistic regression equation, the predicted probability p for the time parameter x can be expressed as

$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x)}} \qquad (1)$$

where β_0 and β_1 are partial regression coefficients. Table 1 shows the calculated partial regression coefficients for each time parameter.

Table 1 Partial regression coefficients for each time parameter

	x	β_0	β_1
Healthy vs Non-healthy	*T1*	1.59	-0.0013
	T2	2.66	-0.0033
Frailty vs Non-frailty	*T1*	-13.71	0.0066
	T2	-7.33	0.0051

Next, we calculated the Area Under Curve (AUC) using the Receiver Operating Characteristic (ROC) curve for the predicted probabilities, and examined whether the discrimination performance of healthy vs. non-healthy and frailty vs. non-frailty was reasonable. AUC of 0.7 or higher was considered to be able to discriminate. Figure 6 shows the ROC curve and AUC for each time parameter. In the healthy vs. non-healthy group, both *T1* and *T2* have low AUCs, which means the healthy group cannot discriminate from the non-healthy group. On the other hand, in the frailty and non-frailty groups, *T1* has the highest AUC (=0.94), followed by *T2* (AUC=0.88), both of which are suitable parameters for identification of frailty.

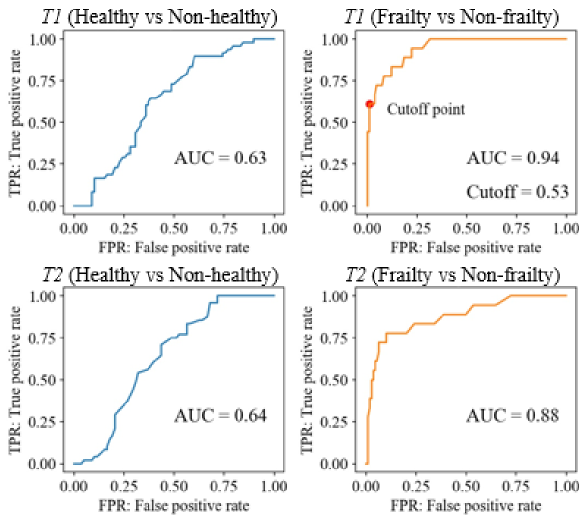

Fig. 6 ROC curve and AUC for each time parameter

Table 2 Performance indexes of frailty discrimination by *T1*

Sensitivity	0.61
Specificity	0.99
Positive predictive value (PPV)	0.92
Negative predictive value (NPV)	0.94

The cutoff values from the ROC curve for *T1*, which had the highest AUC, were investigated for verification of frailty identification. The cutoff values were calculated using a method that considers the cost of misclassification by MATLAB [7]. The optimum cutoff value was 0.53. Therefore, a subject is judged to be a frailty when the predicted probability of *T1* was 0.53 or higher. Table 2 shows the performance indexes of frailty discrimination by *T1*. Table 2 shows that the specificity was 99%, the positive and negative predictive values exceeded 90%. Therefore, the evaluation parameter (*T1*) by the SS-5 test has very high identification rate to detect almost all non-frailty elderly persons, and there is almost no possibility of misclassifying frailty persons as non-frailty. If the non-frailty status is identified with almost certainty, the possibility of falls due to lower limb function decline is low, and they can be recommended to do active exercises and going out. Therefore, this discrimination is very meaningful. In addition, Table 2 shows that the sensitivity is middle at about 60%, but the specificity is 99%, resulting in a positive predictive value of 92%, which means 92% of frailty people who test positive who actually are frailty. In this case some preventive measures or appropriate treatment or training to improve the motion function could be recommend by doctors.

5. Conclusion

The SS-5 tests with the floor reaction force meter were conducted at ordinary speed on healthy elderly, prefrailty, and frailty subjects, and new evaluation parameters were investigated. For identification of frailty and non-frailty group, the stand-up movement time (*T1*) showed high performance to discriminate the frailty and non-frailty group. However, the SS-5 test showed the non-good performance to discriminate the healthy and non-healthy group. The reason might be that the momentum of the SS-5 test at ordinary speed might be too light for prefrailty subjects. The evaluation of prefrailty status will be our next research objective.

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