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Original Article

Intra- and inter-examiner reliability and minimal detectable change for different methods of measuring toe grip strength in healthy adults

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Abstract. [Purpose] This study aimed to compare the inter- and intra-examiner reliabilities of toe grip strength measurements obtained just above the first interphalangeal joint with those of toe grip strength measurements obtained in the most comfortable position for the participant. The study also aimed to calculate the minimal detectable change for the more reliable method. [Participants and Methods] The participants for each test included 20 healthy adult males and females. Intra-class correlation coefficient (1,1) and (2,1) values were calculated for both tests. Bland–Altman analysis was used to determine the systematic error and calculate the minimal detectable change. [Results] The intra- and inter-examiner reliabilities of measurements obtained by setting the position of the toe-grasping bar to the first interphalangeal joint were better than those obtained in the most comfortable position for the participant. Measurement of the minimal detectable change showed a random error of 4.97 kg. [Conclusion] We considered that toe grip strength measurements just above the first interphalangeal joint were better. The minimal detectable change was 4.97 in healthy adults.

Key words: Toe grip strength, Intra- and inter-examiner reliability, Minimum detectable change

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INTRODUCTION

Toe problems have been shown to affect performance, including balance function[1)]. Toe problems are reported in 30% of community-dwelling older adults and can make daily living difficult[2)]. Toe grip strength is related to quadriceps[3)] and is reported to be a risk factor for falls[4)]. In a one-year follow-up study of elderly people by Menz et al.[4)], individuals in the fallen group had significantly lower ankle mobility and toe grip strength than those in the non-fallen group; in addition, more of the former had decreased plantar sensation, as well as foot pain and hallux valgus. Notably, decreased toe grip strength and foot pain were associated with falls[4, 5)]. Therefore, previous studies suggest that toe grip strength is important in balance assessment and treatment of the elderly. However, toe grip strength evaluation is not common in clinical practice, and a standard measurement method has not yet been established[6)]. In order to establish a standard measurement method, it is necessary to examine its reliability and validity.

If relative reliability is high, it indicates that repeated measurements are consistent within and between examiners. Relative reliability is measured with correlation coefficients. The intra-class correlation coefficient (ICC) evaluates correlation based upon variance estimates from analysis of variance. the more common the variance between sets of measurements, the higher ICC. ICC (1,1) represents Intra-examiner reliability. On the other hand, ICC (2,1) represents inter- examiner reliability. ICC

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scores were interpreted as: 0.0 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to0.80, substantial and 0.81 to 1.0, almost perfect agreement[7]. Even if the reliability of repeated measures is excellent, an individual's repeated performance may not be consistent from test to test. Scores may fluctuate when accounting for variations in individual performance and measurement error[8].

The absolute reliability can be used to examine which types of errors are present in the measurements and to what extent they are contained in the measurements[8]. A measure of absolute reliability represents "true" changes in a measurement. Systematic error and random error are two types of errors that can occur during evaluation. In order to clarify the true change, it is required to consider systematic error and random error, which are errors contained in the measurements. Systematic error includes fixed error and proportional error. Fixed error are deviations that occur in a specific direction with a certain width regardless of the true value, whereas proportional error are deviations that occur in a specific direction that increase or decrease in pro-portion to the true value[8]. Bland–Altman analysis is a method for analyzing systematic error, and if the contamination of systematic error is rejected by Bland–Altman analysis, it is random error that reduce the reliability of the measurement[8]. Random error is a variation as a large or small random error in relation to the true value and can be divided into biological individual differences and measurement error that occur during measurement[9]. As a method to examine the measurement error occurred during the measurement, the minimal detectable change (MDC) indicates the critical range in which the change in two measured values obtained by repeated measurements, such as retesting, lies due to measurement error. A change within MDC is believed to be due to measurement error, whereas a change greater than MDC is considered a change greater than measurement error[9]. Identifying MDC can be a useful measure to show the therapeutic effects of physical therapy interventions.

According to previous studies, several methods exist for evaluating toe grip strength, including the paper grip test[10], a pressure platform[5], a modified grip strength meter[11] and a toe grip strength meter[12]. The toe grip strength meter is easy to measure and is used for clinical practice at our hospital. Previous studies have shown that two main methods for evaluating toe grip strength exist: measuring at the position where the person is most comfortable to grip the bar or measuring directly above the first interphalangeal joint. Kito et al.[11] measured toe grip strength as the position where the person is most comfortable to grip the bar and reported high reliability with ICC (1,1) 0.93. Soma et al.[6] examined the appropriate grip position of the toe grip bar at the first interphalangeal joint and reported that the method in which the bar was positioned directly above the first interphalangeal joint showed high reproducibility. Uritani et al.[12] also used the same method of placing the bar at the first interphalangeal joint with ICC (1,1) 0.82–0.91. However, no previous study has examined which of these two methods is more reliable. In addition, we could not find anything that identified MDC in toe grip strength.

The purpose of this study is to compare whether the method of measuring toe grip strength just above the first interphalangeal joint or the method of measuring toe grip strength in the most comfortable position for the participant has higher inter- and intra-examiner reliability. The study also aimed to calculate MDC of the more reliable method. This study was performed on healthy adults as a pre-liminary study on patients.

PARTICIPANTS AND METHODS

In test 1, 20 healthy adult males and females (14 males, 6 females; age: 25 ± 4.6 years; height: 167.9 ± 6.5 cm; weight: 60.5 ± 8.6 kg [mean ± standard deviation]) were included, and in test 2, 20 healthy adult males and females (10 males, 10 females; age: 23.9 ± 2.3 years; height: 164.5 ± 7.2 cm; weight: 57.3 ± 8.9 kg) were included. A total of 40 feet on each side were evaluated. All participants were volunteers recruited from the staff of our hospital. In both tests, we excluded those with a history of foot problems. All participants provided written informed consent prior to participating in the study. Although some of the participants were switched between the two tests, there was no statistically significant difference, and we concluded that there was no change in the subject characteristics. Two examiners were assigned to the study. The measuring instrument used was a toe grip dynamometer (Takei Scientific Instruments, Niigata, Japan). The measurement was performed in a sitting position at the platform, with the upper limbs in a comfortable position, the hip and knee joints flexed 90° and the ankle joints dorsiflexed 0°, based on previous studies[11]. The position of the toe grasping bar was set to the part of the foot that the participant could grasp most easily, and the ankle was fixed with a strap for measurement. During the measurement, the examiner immobilized the toe grip dynamometer. If the participant was not tall enough and if the hip and knee joints were not at 90°, the measurement was performed using a footrest. After practicing, measurements were taken twice each on the left and right foot. Every measurement was given a break of at least 30 seconds. To examine the intra- and inter-examiner reliability, the same participant was measured again by another examiner after a period of at least three days but no more than seven days, considering muscle fatigue and learning effects[13]. The testing order of examiners A and B was randomized. In test 2, measurements were taken with the first interphalangeal joint placed directly above the bar (Fig. 1).

For statistical analysis, ICC (1,1) and ICC (2,1) were calculated for test 1 and test 2, respectively, and then Bland–Altman analysis was used to determine the presence or absence of systematic error and to calculate MDC using R 4.0.2, the Comprehensive R Archive Network freeware, for statistical analysis. In Bland–Altman analysis, the difference between a pair of measurements was plotted on the y-axis, and the average of the two measurements was plotted on the x-axis (Bland–Altman plot) to visually confirm the presence or absence of systematic errors in the measurements[8]. In case there were no fixed and proportional errors, the value of the minimum detectable error (MDC) was calculated. A significance level of $p<0.05$ was used.

RESULTS

In test 1, toe grip strength measured by examiner A was 21.03 (5.49) the first time and 21.25 (5.81) the second time; ICC (1,1) was 0.92 (0.86–0.96). Toe grip strength measured by examiner B was 17.9 (5.5) the first time and 19.5 (4.88) the second time; ICC (1,1) was 0.70 (0.50–0.83). ICC (2,1) was 0.80 (0.51–0.91) (Table 1). Bland–Altman analysis showed that there was no fixed error for examiner A and MDC was 4.33. A fixed error was observed for examiner B (Table 2).

In test 2, toe grip strength measured by examiner A was 19.53 (5.89) the first time and 20.26 (6.11) the second time; ICC (1,1) was 0.94 (0.88–0.97). Toe grip strength measured by examiner B was 18.21 (5.46) the first time and 18.81 (5.80) the second time; ICC (1,1) was 0.90 (0.81–0.94). ICC (2,1) was 0.88 (0.73–0.94) (Table 1). In test 2, the fixed error was confirmed for examiner A, but no fixed error was observed for examiner B, resulting in MDC of 4.97. No proportional error was observed during tests 1 and 2 (Table 2).

DISCUSSION

The purpose of this study was to investigate a more reliable measurement method for toe grip strength and to clarify the measurement error in toe grip strength. The mean of toe grip strength in this test was not significantly different from that in previous studies[12], and there was no problem in the selection of the participants.

In test 1, ICC (1,1) for examiner A was 0.92 (0.86–0.96) and that for examiner B was 0.70 (0.50–0.83). The reliability of examiner B was not very high, considering the confidence interval by Landis JR et al[7]. In test 2, ICC (1,1) of examiner A was 0.94 (0.88–0.97) and that of examiner B was 0.90 (0.81–0.94) (Table 1). Comparing test 1 and test 2, ICC of examiner A was higher than that of examiner B in both tests. Examiner A in test 1 showed a higher reliability than examiner B in test 2, but

Fig. 1. The position of the toe grasping bar of test 1 was set to the part of the foot that the participant could grasp most easily. In test 2, different from test 1, measurements were taken with the first interphalangeal joint placed directly above the bar.

Table 1. Intra- and inter-examiner reliability of toe grip strength

		TGS 1st (kg)	Mean SD	TGS 2st (kg)	Mean SD	ICC (1,1) (95% CI)	ICC (2,1) (95% CI)
Test 1	Exam A	21.0	5.5	21.3	5.8	0.92 (0.86–0.96)	
	Exam B	17.9	5.5	19.5	4.9	0.70 (0.50–0.83)	0.80 (0.51–0.91)
Test 2	Exam A	19.5	5.9	20.3	6.1	0.94 (0.88–0.97)	
	Exam B	18.2	5.5	18.8	5.8	0.90 (0.81–0.94)	0.88 (0.73–0.94)

Exam: Examiner; SD: standard deviation; TGS: toe grip strength; CI: confidence interval.

Table 2. Assessment of Bland–Altman analysis

		SE	Limits of agreement	95%CI for mean of difference	Slope of the regression line	Fixed bias	Proportional bias	MDC
Test 1	Exam A	0.35	−3.33, 2.88	−0.93, 0.48	−0.15	No	No	4.33
	Exam B	0.60	−6.98, 3.76	−2.83, −0.39	0.17	Yes	No	
Test 2	Exam A	0.32	−3.58, 2.14	−1.37, −0.07	−0.11	Yes	No	
	Exam B	0.40	−4.17, 2.97	−1.41, 0.21	−0.14	No	No	4.97

Exam: Examiner; SE: standard error; MDC: Minimum Detectable Change.

the confidence interval for examiner B in test 1 was 0.50–0.83, indicating a wide range of measurements. In contrast, in test 2, the reliability of both A and B was high and the confidence interval was narrow at 0.81–0.94. This indicated that setting the position of the toe grip bar to the first interphalangeal joint had better intra-examiner reliability.

ICC (2,1) was 0.80 (0.51–0.91) in test 1 and 0.88 (0.73–0.94) in test 2, indicating that the inter-examiner reliability was higher in test 2. From this test, it was found that placing the toe grip bar at the first interphalangeal joint was more reliable for the measurement of toe grip strength.

Next, we determined the systematic error of toe grip strength by Bland–Altman analysis. Fixed error was observed for examiner B in test 1 and for examiner A in test 2 (Table 2). The results showed that the fixed error values tended to be negatively biased. This indicated that the values of toe grip strength were higher in the second measurement. The measurement of toe grip strength differs from the measurement of hand-grip strength in that the former is a movement not usually used in daily life. Therefore, we thought that the participants who were not experienced in the measurement tended to strengthen their grip the second time. The difference in the level of proficiency in toe grip strength may have affected the measurement.

In addition, no proportional error was found in any of the measurements in this study. In the measurement of toe grip strength, it was found that regardless of the size of the participant's force, there was no deviation that increased or decreased proportionally to the true value or occurred in a specific direction. In the measurement of toe grip strength, the possibility of fixed error was considered, regardless of the grip position. Therefore, it may be possible to minimize the error by repeating the measurement two or more times to confirm no large difference.

MDC which is a random error was calculated to be 4.33 kg in test 1 and 4.97 kg in test 2. Fukuda and Kobayashi[14] reported that four types of toe training were performed on healthy subjects three times a week for six weeks. As a result, amount of change in toe grip strength was 2.8 kg, and this resulted in improvements in stride length and walking speed. Considering the previous study that a 2.8 kg improvement in toe grip strength improved walking speed, we think that 4.97 kg is a large change in the case of showing the effect of physical therapy. if the change in toe grip strength before and after the treatment was approximately 5 kg or more, it would be considered to be an effect exceeding random error. Therefore, in such a case, we would consider that the treatment effect was sufficient. However, when evaluating the results, validity as well as reliability should be considered. It is also important to combine other assessments. We have to be careful in measuring toe grip strength, because there will be a random error of 4 kg to 5 kg.

One of the limitations of this study is that toe grip strength is greatly affected by age and begins to decline in people in their 50s, with a significant decline after their 60s[15]. Since the participants in this study were young healthy adults, it is difficult to apply the results of this study to the elderly or patients with medical problems.

In conclusion, this study found that measuring toe grip strength with the position of the toe grip bar at the first interphalangeal joint was more reliable, and MDC was 4.97 in healthy adults. This study was a pre-study of patients. In the future, we will study MDC in patients and utilize the results in clinical practice.

Conflicts of interest

There is no conflict of interest in this study.

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