Reference equation for the incremental shuttle walk test in Japanese adults

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ABSTRACT

Background: The incremental shuttle walk test (ISWT) is widely used in clinical and research settings. However, there are no reference equations to predict the walk distance achieved in the ISWT (ISWD) for healthy Japanese adults. We aimed to establish a reference equation for the ISWD prediction in Japanese adults.

Methods: The sample comprised 590 healthy Japanese subjects (237 male). All subjects performed the ISWT twice, and their anthropometric and demographic data were collected, including gender, age, height, weight, and body mass index (BMI).

Results: Subjects walked 640 [490–793] m in the ISWT. The ISWD correlated ($p < 0.001$ for all) with age ($r = -0.51$), gender ($r = 0.56$), weight ($r = 0.39$), and height ($r = 0.62$), but not with BMI ($r = -0.01$, $p = 0.74$). The stepwise multiple regression model showed that age, gender, and height were independent contributors to the ISWT in healthy subjects, explaining 50% of the variability. The reference equation for the ISWD was: ISWD(m) = – 4.894 – 4.107 × Age (years) + 131.115 × Gender + 4.895 × Height (cm), where male gender = 1.

Conclusion: We have established a reference equation for the ISWD prediction in Japanese adults. The prediction accuracy was high ($R^2 = 50\%$), and a reference equation was established using anthropometric and demographic variables that can be easily assessed in clinical settings. The reference equation developed in this study will be useful for evaluating the magnitude of exercise intolerance in Japanese adults.

Keywords: Reference value, Incremental shuttle walk test, Exercise test, Statistical regression

Abbreviations: 6MWT (six- minute walk test), ISWT (incremental shuttle walk test), $\dot{V}O_2$ peak (peak oxygen uptake), SpO_2 (percutaneous oxygen saturation), PR (pulse rate), %HRmax (percentage of the predicted HRmax), ISWD (the walk distance in ISWT), COPD (chronic obstructive pulmonary disease), BMI (body mass index), 15mISWRT (15m incremental shuttle walk and run test)

1. Introduction

Exercise intolerance is a common presentation and prognostic indicator in chronic disease. Therefore a need exists to quantify exercise tolerance, and assess response to therapeutic interventions. Currently, field exercise tests such as the six-minute walk test (6MWT) and incremental shuttle walk test (ISWT) are widely used to assess exercise tolerance and prescribe training intensity in pulmonary rehabilitation programs [1]. Although these tests were developed in patients with cardiopulmonary diseases [2, 3], their use has been validated in a wide range of chronic diseases [4, 5] in part due to their operational simplicity.

The 6MWT is the most widely used in the field walking tests in Japanese clinical setting, because it is simple and inexpensive to perform [2]. However, the main disadvantage is that the patient's exercise tolerance is underestimated, as it allows the patient to set the walking speed. As an alternative to self-paced tests and in an attempt to improve standardization and reproducibility, the ISWT was developed by Singh et al. [3]. The ISWT [3] is an externally paced incremental walking test which evaluates maximal exercise capacity. In individuals with chronic obstructive pulmonary disease (COPD), the distance walked (incremental shuttle walk distance [ISWD]) correlates more strongly with peak oxygen uptake ($\dot{V}O_2$ peak) than the 6MWT distance and has good reliability [6]. Therefore, it is possible to use the predicted $\dot{V}O_2$ peak, from the ISWD, for exercise prescription. The ISWT has been used to assess the response to interventions [7-10], identify oxygen desaturation during exertion [11], and predict mortality [12] and exacerbations [13] in chronic respiratory disease. In healthy individuals, the ISWT has proven useful for quantifying the benefits of a walking training program [14].

Despite the widespread use of the ISWT, there are no reference equations to predict the ISWD achieved by healthy Japanese adults. Such an equation is necessary to determine the magnitude of exercise intolerance.

Although equations exist for the ISWD prediction in European, American, and Brazilian adults [15-18], compared with these populations, Japanese individuals have a smaller physique, (e.g. height, weight, and body mass index (BMI) [19, 20],). In addition, we hypothesized that existing equations may not be applicable to Japanese samples. In this study, we aimed to establish a reference equation for the ISWD prediction in Japanese adults and to compare measured ISWD with predicted ISWD derived from an existing equation (Probst et al.) [18].

2. Materials and methods

2.1. Subjects

Five hundred and ninety-nine healthy Japanese male and female volunteers, aged between 20 and 90 years, were recruited which include staff at 13 hospitals (Nagasaki, Kitakyushu, Kagoshima, Ise, Kurashiki, Ogaki, Yamaguchi, Okinawa, Oita, and Tokyo), staff and students at four universities (Nagasaki, Kio, Health Science, and Kumamoto Health Science), and participants in community health classes for elderly people (total of 20 facilities). Data were collected between September 2013 and October 2015. The study was approved (approval date; 8/8/2013, number; 13080844) by the Ethics Review Committee of Nagasaki University Graduate School of Biomedical Sciences. Written informed consent was obtained from all participants.

Exclusion criteria were any health problem that could interfere with the ability to perform physical exercise: e.g. cardiovascular, respiratory, neuromuscular, or musculoskeletal disease; upper respiratory tract infection within the previous month; and history of stroke, severe dementia and mental disorders, and visual and hearing impairment. However, subjects with well-controlled hypertension and former smokers without tobacco-related diseases were included. If no problems were identified during the health screening check, subjects' exercise capacity and anthropometric and demographic data were evaluated. Gender, age, height, weight, and BMI were collected on the day they performed the ISWT.

2.2. Incremental shuttle walk test

The ISWT was performed according to the original protocol [3]. Subjects performed the test twice (separated by a rest period of at least 30 minutes). To allow for the known learning effect [21], the results of the second ISWT were recorded for analysis. Subjects were required to walk along a level 10-m course, marked by 2 cones placed 9-m apart at a speed dictated by signals from an audio

CD. The walking speed increased each minute (initial walking speed was 0.5 m/s and increased by 0.17 m/s each minute), for a total of 12 levels. Subjects were not permitted to jog or run during the test. The maximum achievable distance is 1020 m. All ISWTs were supervised by a physiotherapist at the facility who was experienced with the ISWT. Criteria for test termination were failure to maintain the required speed or symptoms. Oxygen saturation (SpO_2), pulse rate (pulse oximeter, Pulsox-Me300, Minolta, Osaka, Japan), and perceived dyspnea and leg fatigue (modified Borg scale [22]) were assessed prior to and immediately upon test termination.

2.3. Statistical analysis

The distribution of the data was assessed using Kolmogorov-Smirnov test and frequency histograms. Data are described as median [interquartile range 25%–75%]. The Mann-Whitney test was used to compare the subjects' characteristics and measures obtained from the ISWT between males and females. Spearman's correlation coefficients were calculated to examine the relationship between variables (age, gender, height, weight, and BMI) and the ISWD. Multiple linear regression analysis was used to evaluate the best predictor variables for the ISWD and to generate the regression equation.

The measured ISWD was compared with the predicted ISWD derived in a Brazilian sample [18] (subjects aged 18–83 years) using scatter plots and Wilcoxon rank sum test. No comparisons were made with other predicted equations because they are only applicable to individuals aged over 40 years or required variables (e.g. lower limb strength or physical activity) that were not assessed in our study [15-17]. The level of statistical significance was set at 5%. All analyses were performed using the statistical software program IBM SPSS ver. 21 for Windows (IBM SPSS, Tokyo, Japan).

3. Results

The study sample comprised 599 subjects. Data from nine subjects were not included because they terminated the test prematurely due to severe joint pain. The characteristics of the remaining 590 subjects (237 males and 353 females) are summarized in Table 1.

Subjects walked 640 [490–793] m in the ISWT and reached 81 [71–90]% of their maximal predicted HR (220 – age in years) [23]. In 63 subjects (56 males, 7 females), there was a ceiling effect for the test. In the remaining 527 subjects, the test was terminated because they were unable to keep up with the speed (482 [82%]) and symptoms (leg fatigue in 28 subjects; dyspnea in nine subjects and other symptoms in eight subjects). Three subjects reported low back and knee pain that ceased immediately on test termination. No other adverse events were reported.

Significant correlations were observed between the ISWD and age ($r = -0.51$), gender ($r = 0.56$), weight ($r = 0.39$), and height ($r = 0.62$) ($p < 0.001$ for all), but no relationship with BMI ($r = -0.01$, $p = 0.74$) was observed. Stepwise multiple regression showed that age, gender, and height were independent contributors to the ISWD, explaining 50% of the variance. Unstandardized coefficients, partial correlations, and significance are shown in Tables 2 and 3. The reference equation for the ISWD was:

ISWD (m) = – 4.894 – 4.107 × Age (years) + 131.115 × Gender + 4.895 × Height (cm)

(where male = 1).

Comparisons between the measured ISWD and ISWD derived in a Brazilian sample are shown in Figure 1. Distances derived using the equation [18] significantly overestimated the measured ISWD. The mean estimated ISWD was 911 [677–1079] m compared to the measured ISWD of 640 [490–793] m ($p < 0.001$).

4. Discussion

This is the first study to develop a reference equation to predict the ISWD in a healthy Japanese population. A large part (50%) of the variance in the ISWD was explained by age, gender, and height. The amount of variance explained ($R^2 = 0.5$) was similar to that previously reported [17]. This reference equation is a useful tool in evaluating the ISWT results obtained from patients. Since the ISWT is an externally paced walk test, the interference such as operator encouragement and motivation is lower. Therefore, this reference equation derived in the present study can be useful in other populations.

Recently, both British and Brazilian researchers have reported a reference equation for the ISWT [15-18]. Our sample included a larger number of subjects (590 vs 90 to 242) compared to these studies [15-18]. Further, other studies were restricted to subjects aged ≥ 40 years [15-17]. Moreover, we established an equation using anthropometric and demographic variables which can be easily applied in clinical settings. Therefore, the reference equation we developed will be useful in determining the presence and extent of exercise intolerance in clinical populations.

In our study, the demographic and anthropometric variables identified as independent predictors of the ISWD were age, gender, and height. Our findings are consistent with published data relating to exercise tolerance and walking ability which have shown a relationship with age [24-30], gender [25, 27, 28], and height [25, 27, 28, 31]. The negative influence of advanced age on the ISWD is explained by a decline in skeletal muscle function and $\dot{V}O_2$ peak that typically occurs parallel with aging [29, 30]. In our study, males walked further than females, as has been described for the ISWT previously [15, 17, 18], most likely due to males having higher absolute muscle strength and mass and height [32]. Previous studies for the 6MWT and ISWT observed an association between height and walking distance in healthy adults [15, 17, 33, 34]. The strong influence of height is attributable to stride length, a major predictor of walking speed [31].

Weight and BMI were not identified as independent predictors of the ISWD in contrast to earlier studies [15-18]. Very few of the subjects in our study were overweight. Further, our sample had a narrower weight range and BMI than subjects in studies that developed a prediction equation for the ISWD in European and American samples [15-18]. In studies that generated a reference equation for the 6MWT, Poh et al. [34] reported that equations derived from Caucasian subjects overestimated 6MWD in Singaporeans of Chinese origin due to differences in physique. Regression equations derived in Caucasian subjects [18] overestimated the ISWD for our Japanese sample. Future studies are needed to determine if our equation is applicable to individuals of other Asian origin.

In the present study, subjects reached 81 [71–90]% of their maximal predicted HR during the ISWT, a value lower than in the previous study [18]. This may be explained by variations in the ISWT protocol. Since the ISWT was developed to assess functional exercise capacity in patients with respiratory diseases, the original protocol consists of 12 levels. However, to avoid the ceiling effect in healthy subjects, Probst et al. [18] used the modified protocol, permitting subjects to run in order to maintain the speed. However, the original ISWT was used consistently with that in clinical settings (i.e. 12 levels, no running) within Japan, and the predominant reason for ISWT termination was the inability to maintain the required speed. In our study, of the 63 subjects (10.7%) who completed level 12, most were males aged 20 to 30 years. In previous studies in Japan, Mikawa et al. [35] reported the utility of the 15m incremental shuttle walk and run test (15m ISWRT) in young and middle-aged healthy individuals and showed a strong correlation with $\dot{V}O_2$ peak (r=0.86) and concluded that the test is valid and safe in evaluating $\dot{V}O_2$ peak in adults. Our findings suggest that the ISWT is not suitable in evaluating exercise tolerance in young healthy males. Therefore, clinicians and researchers should choose either the ISWT or 15m ISWRT based on the age and expected exercise tolerance of their sample.

Some limitations of our study should be considered. First, consistent with other studies that developed reference values for field walking tests [15, 17, 18], we used a convenience sample, which is likely to have introduced bias albeit our sample was large and included similar numbers of male and female subjects in each decade. Second, a few variables which could contribute to the variance in the ISWD were not assessed, such as pulmonary function [15-18] and peripheral muscle force [16]. However, additional equipment and expertise are necessary to collect such variables.

5. Conclusions

We have established a reference equation for the ISWD prediction in Japanese adults. The prediction accuracy was high (R^2 = 50%), and the equation was established using age, height, and gender which can be easily collected in clinical settings. The reference equation will be useful in evaluating the extent of exercise intolerance in Japanese samples.

Conflict of interest

The authors have no conflicts of interest.

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Appendices

Table 1 Demographics and incremental shuttle walk test data (n=590).

Data are expressed as median [interquartile range 25–75%].

BMI: body mass index. ISWD: incremental shuttle walk distance. PR: pulse rate. %HRmax: percentage of the predicted HRmax (220 – age) reached at the end of the walk test.

Completer: those who completed 12 levels of ISWT.

Table 2 Relationships between gender and anthropometric variables with incremental shuttle walk distance.

r: Spearman correlation coefficient

Table 3 Multiple linear regression analysis with incremental shuttle walk distance as the dependent variable.

B: Unstandardized coefficients, CI: Confidence interval for B

Residual standard deviation = 145.8m

Reference equation: ISWD (m) = – 4.894 – (4.107 × Age) + (131.115 × Gender) + (4.895 × Height)

[a]: male = 1

Fig. 1 Scatter plot of the measured ISWD and predicted ISWD from Probst et al.

Table1 Demographics and incremental shuttle walk test data (n=590).

	Age bands, Total n (men)				
	20–39 y, 249 (129)	40–59 y, 192 (73)	60–79 y, 131 (30)	≥80 y, 18 (5)	Overall, 590 (237)
Age (years)	28 [25–33]	48 [44–53]	69 [64–74]	83 [81–85]	44 [31–60]
Height (cm)	165 [158–172]	161 [156–169]	153 [150–159]	151 [146–160]	161 [154–168]
Weight (kg)	57 [50–68]	57 [50–66]	54 [49–62]	54 [49–58]	56 [50–65]
BMI (kg/m^2)	20.8 [19.5–22.9]	21.7 [20.0–23.5]	23.0 [21.5–24.9]	22.7 [21.3–24.8]	21.6 [19.9–23.7]
ISWD (m)	750 [575–915]	640 [530–745]	480 [420–560]	350 [200–410]	640 [490–793]
Completer (%)	49 (8.3)	14 (2.3)	0	0	63 (10.7)
PR before (bpm)	78 [70–86]	80 [72–88]	73 [65–82]	65 [63–75]	77 [70–86]
PR end (bpm)	151 [136–164]	146 [125–160]	120 [108–141]	110 [90–129]	144 [121–160]
%HR max (%)	79 [71–86]	85 [74–95]	82 [71–93]	79 [67–94]	81 [71–90]
SpO_2 before (%)	98 [97–99]	98 [97–99]	97 [97–98]	97 [97–98]	98 [97–99]
SpO_2 end (%)	96 [95–98]	96 [95–97]	96 [94–98]	96 [93–98]	96 [95–98]
Dyspnea before	0 [0–0]	0 [0–0]	0 [0–1]	0 [0–2]	0 [0–0]
Dyspnea end	4 [4–5]	4 [3–6]	4 [4–5]	4.5 [4–5]	4 [4–5]
Leg effort before	0 [0–0]	0 [0–0]	0 [0–1]	0 [0–2]	0 [0–0.5]
Leg effort end	5 [4–7]	4 [3–7]	4 [2–5]	4 [2.8–5.5]	5 [3–7]

Data are expressed as median [interquartile range 25–75%].

BMI: body mass index. ISWD: incremental shuttle walk distance. PR: pulse rate. %HRmax: percentage of the predicted HRmax (220 – age) reached at the end of the walk test.

Completer: those who completed 12 levels of ISWT.

Table 2 Relationships between gender and anthropometric variables with incremental shuttle walk distance.

	r	p-value
Age (years)	- 0.51	<0.001
Gender	0.56	<0.001
Height (cm)	0.62	<0.001
Weight (kg)	0.39	<0.001
BMI (kg/m^2)	- 0.01	0.747

r: Spearman correlation coefficient

Table 3 Multiple linear regression analysis with incremental shuttle walk distance as the dependent variable.

	B	95%CI		Partial correlation	p-value
		Lower limit	Upper limit		
Constant	– 4.894	– 355.090	345.301		0.978
Age (years)	– 4.107	– 4.859	– 3.355	– 0.355	<0.001
Gender [a]	131.115	92.886	169.343	0.311	<0.001
Height (cm)	4.895	2.757	7.034	0.225	<0.001

B: Unstandardized coefficients, CI: Confidence interval for B

Residual standard deviation = 145.8m

Reference equation: ISWD (m) = – 4.894 – (4.107 × Age) + (131.115 × Gender) + (4.895 × Height)

[a]: male = 1

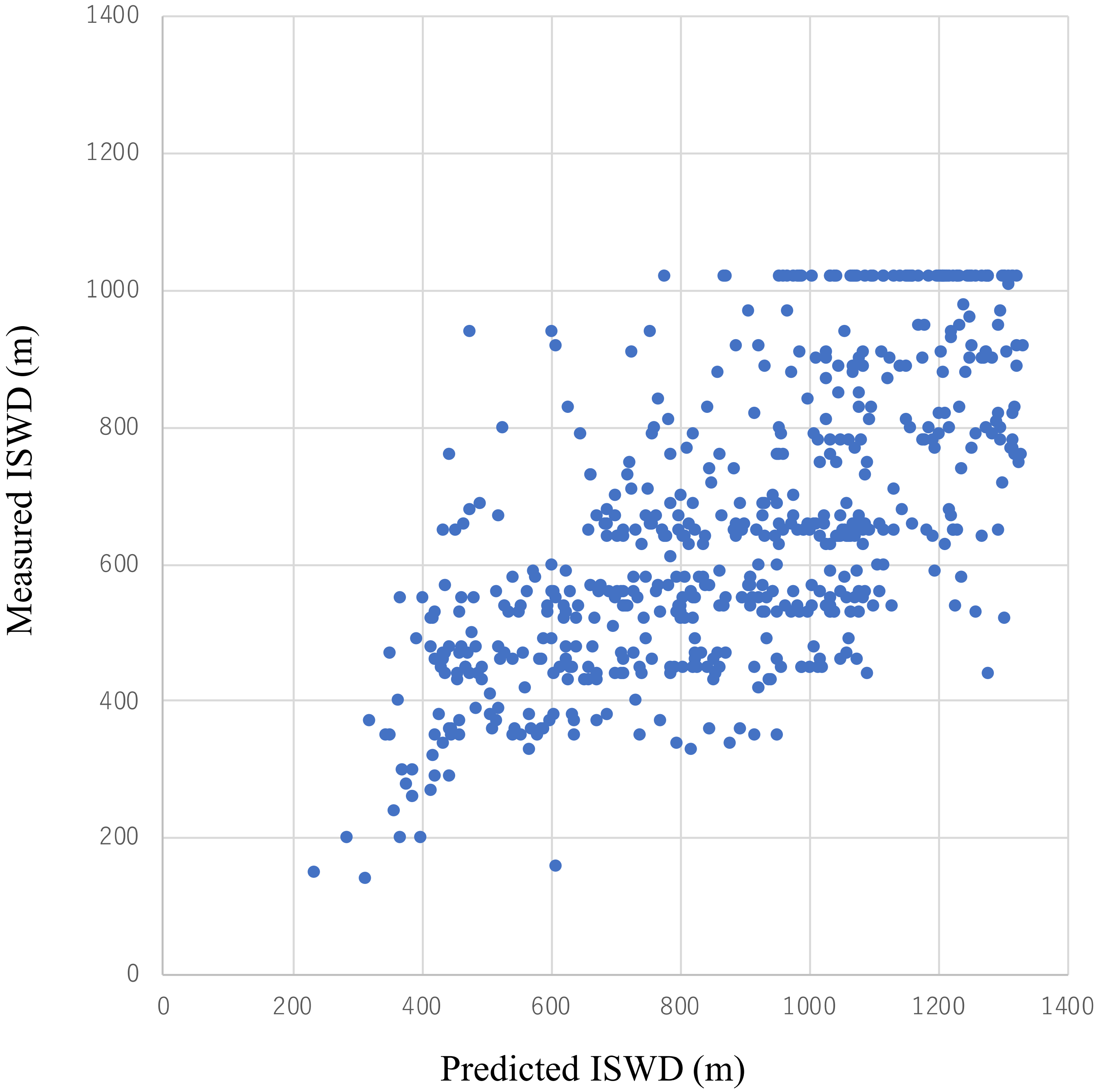

Figure 1 Scatter plot of measured ISWD and predicted ISWD from Probst et al.