Incremental shuttle and six-minute walking tests in the assessment of functional capacity in chronic heart failure

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BACKGROUND: The incremental shuttle test presents some theoretical advantages over the six-minute walk test in chronic heart failure (CHF), including better standardization and less dependency on collaboration.

OBJECTIVES: The present study evaluated test-retest repeatability, test accuracy in predicting a peak oxygen consumption (VO_2) of 14 mL/kg/min or less, as well as the prognostic value of both walking tests in stable CHF patients.

METHODS: Sixty-three patients (44 men; New York Heart Association functional class II to IV) underwent an incremental treadmill exercise test and, on another day, the walk test in duplicate.

RESULTS: Patients showed well-preserved functional capacity according to the distance walked in both tests (six-minute walk test 491 ± 94 m versus incremental shuttle walk test 422 ± 119 m; $P < 0.001$). Interestingly, the six-minute and incremental shuttle walk test differences in distance walked were higher in more disabled patients. The mean bias $\pm 95\%$ CI of the within-test differences were similar (7 ± 40 m and 8 ± 45 m, respectively). Peak VO_2 , but not distance walked in either test, was associated with survival ($P < 0.05$).

CONCLUSIONS: The incremental shuttle walk test showed similar repeatability and accuracy in estimating peak VO_2 compared with the six-minute walk test in CHF patients. Direct measurement of peak VO_2 , however, remains superior to either walking test in predicting survival – at least in patients with well-preserved functional capacity.

Key Words: Exercise tolerance; Heart failure; Oxygen consumption; Prognosis; Walking

The cardiopulmonary exercise test, with direct measurements of peak oxygen consumption (VO_2), has been found to provide a reliable and externally valid index of functional capacity in chronic heart failure (CHF), especially for death risk stratification and early indication of transplantation (1). The widespread use of cardiopulmonary exercise testing has been hampered because of the need for cumbersome and expensive gas analyzers. In addition, the cardiopulmonary exercise test is not well-tolerated in many patients, and trained staff are required. Alternatively, field exercise tests, such as the six-minute walk test, have been progressively advocated as an advantageous strategy in this patient population (2-5). Despite some recent advances (6,7), however, the six-minute walk test is not a rigidly standardized method, being influenced by patient collaboration and level of encouragement. In addition, the test requires a large space to be performed (at least a 30 m long corridor); its correlation to peak VO_2

Tests de marche progressive et marche de six minutes pour l'évaluation de la capacité fonctionnelle dans l'insuffisance cardiaque chronique

HISTORIQUE : Le test de marche progressive présente certains avantages théoriques par rapport au test de marche de six minutes dans l'insuffisance cardiaque chronique (ICC), y compris une meilleure standardisation et une dépendance moindre à l'égard de l'aspect collaboratif.

OBJECTIFS : La présente étude a évalué la reproductibilité entre test et retest, la précision des tests à prédire la consommation d'oxygène de pointe (VO_2) de 14 mL/kg/min ou moins, de même que la valeur pronostique des deux tests de marche chez des insuffisants cardiaques stables.

MÉTHODES : Soixante-trois patients (44 hommes; classe II à IV de la *New York Heart Association*) ont subi une épreuve d'effort progressive sur tapis roulant et un autre jour, ils ont subi le test de marche dupliqué.

RÉSULTATS : Les patients ont montré une capacité fonctionnelle bien préservée, selon la distance parcourue lors des deux tests (test de marche de six minutes 491 ± 94 m contre test de marche progressive 422 ± 119 m; $P < 0,001$). À noter : la différence entre le test de six minutes et le test progressif pour ce qui est de la distance parcourue a été plus marquée chez les patients plus incapacités. Le biais moyen $\pm$ IC à 95 % pour les différences entre les deux tests du même type a été similaire (7 ± 40 m et 8 ± 45 m, respectivement). La VO_2 de pointe, et non la distance parcourue lors de l'un ou l'autre test, a été associée à la survie ($P < 0,05$).

CONCLUSIONS : Chez des insuffisants cardiaques chroniques, le test de marche progressive a donné lieu à une reproductibilité et à une précision similaires pour ce qui est d'estimer la VO_2 de pointe, comparativement à la marche de six minutes. La mesure directe de la VO_2 de pointe reste par contre supérieure aux deux tests pour ce qui est de prédire la survie, du moins chez les patients qui présentent une capacité fonctionnelle bien préservée.

is only moderate, and the prognostic value of the distance walked remains controversial – as recently reviewed by Faggiano et al (8). In contrast, the incremental shuttle walk test is a more standardized procedure and, due to the progressive increase in exercise intensity, may correlate with peak VO_2 better than the six-minute walk test (9-14).

The present study aimed to comparatively evaluate the safety, reproducibility and accuracy of predicting peak VO_2 and prognostic value of the incremental shuttle walk test compared with the six-minute walk test in a group of symptomatic patients with stable CHF.

METHODS

Subjects

The study population comprised 63 patients (44 men) with established CHF and left ventricular systolic dysfunction (ejection fraction lower than 35% by radionuclide ventriculography), in New York

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TABLE 1
Characteristics of the study population (n=63)

Characteristic	
Age, years (mean $\pm$ SD)	51.3 $\pm$ 10.2
Sex, n (%)	
Male	44 (69.8)
Female	19 (30.2)
Etiology, n (%)	
Idiopathic	30 (47.6)
Chagas' disease	16 (25.4)
Ischemic	8 (12.7)
Other	9 (14.3)
New York Heart Association functional class, n (%)	
II	29 (46.0)
III	30 (47.6)
IV	4 (6.4)
Resting hemodynamics (mean $\pm$ SD)	
Heart rate, beats/min	71 $\pm$ 13
Systolic blood pressure, mmHg	105 $\pm$ 19
Diastolic blood pressure, mmHg	68 $\pm$ 11
Electrocardiogram, n (%)	
Sinus rhythm	57 (90.5)
Atrial fibrillation	2 (3.1)
Pacemaker	4 (6.4)
Holter monitor, n (%)	
Nonsustained ventricular tachycardia	28 (44.4)
Radionuclide angiographic data, % (mean $\pm$ SD)	
Left ventricular ejection fraction	24 $\pm$ 5.6
Echocardiographic data, mm (mean $\pm$ SD)	
Left ventricular end-diastolic dimension	71.4 $\pm$ 10.9
Left ventricular end-systolic dimension	61.1 $\pm$ 11.9
Drugs, %	
Angiotensin-converting enzyme inhibitors	100
Diuretics	92.0
Beta-blockers	90.4
Spironolactone	87.3

Heart Association functional class II to IV. All patients were able to walk without assistance from another person. Exclusion criteria included clinical instability, complex arrhythmias, uncontrolled hypertension, acute myocardial infarction in the preceding three months, unstable angina, chronic or acute lung disease, and musculoskeletal limitations to exercise. Population characteristics are presented in Table 1. Most patients had moderate to advanced idiopathic or Chagas' disease-related CHF. All patients were being administered optimal medical therapy, which included angiotensin-converting enzyme inhibitors, diuretics, beta-blockers and spironolactone. Medical treatment did not change during the study period. The study protocol was submitted to and approved by the Institutional Medical Ethics Committee, and patients gave informed consent.

Protocol

After clinical evaluation and a maximum incremental cardiopulmonary exercise test (to obtain peak VO_2), patients were randomly assigned to four walk tests 30 min apart (two incremental shuttle walk tests and two six-minute walk tests) on a different day. For the purpose of prognostic evaluation, patients were followed-up by means of periodical clinical examination and telephone contact. A cardiovascular event was established if a patient was hospitalized due to a severe exacerbation of CHF or cardiac transplantation, or death due to the cardiac disease.

Cardiopulmonary exercise test

The test was performed on a motorized treadmill with breath-by-breath determination of VO_2 (Vmax 29c, SensorMedics, USA). The

equipment was recalibrated before each test using a gas calibration mixture of known concentration. Test data were averaged every 20 s and peak VO_2 was the highest value recorded. Heart rate and rhythm were continuously recorded by 12-lead electrocardiogram. The VO_2 at the estimated anaerobic threshold was obtained using the modified V-slope (15) and ventilatory (16) methods. Borg scores of perceived exertion were obtained at exercise cessation (6 = "nothing at all" to 20 = "maximal effort").

Six-minute walk test

The six-minute walk test was conducted by a single physiotherapist according to current standards (6,7) in a 30 m long internal corridor. Two tests were performed 30 min apart. Participants were instructed to "walk from end to end of the corridor at your own pace, in order to cover as much ground as possible". Each minute, the investigator encouraged the participants with the standardized statements. Participants were allowed to stop and rest during the test, but were instructed to resume walking as soon as they were able to do so. During the test, cardiac rhythm was continuously followed by a Holter monitor (Dynamis 3000, Brazil) and heart rate was recorded on a heart rate counter (Polar Accurex Plus, Finland). On exercise cessation, the distance walked was determined, and the systolic and diastolic blood pressures were measured. In addition, participants were shown a Borg perceived exertion scale. Values of distance walked were compared with the sex-specific reference values suggested by the American Thoracic Society guidelines (7).

Incremental shuttle walk test

The incremental shuttle walk test was performed according to the original protocol proposed by Singh et al (9). Patients were required to walk along a level 10 m course at a previously determined speed dictated by signals from an audio tape recorder. The walking speed was progressively increased at 1 min intervals, for a total of 12 stages. The test was terminated if the patient was unable to continue at the desired speed or if the patient failed to complete the shuttle course in the allowed time. Patients were continuously monitored by an electrocardiogram monitor (Dynamis 3000, Brazil). As with the six-minute walk test, systolic and diastolic blood pressures, heart rate, perceived exertion (Borg's 6 to 20 category ratio scale) and distance walked were determined on exercise cessation.

Statistical analysis

After certification of data normality (Kolmogorov-Smirnov), data were expressed as mean ($\pm$ SD), with the exception of Borg scores, which were expressed as median and range. Paired Student's *t* test was used to compare the responses between the two tests. Pearson's product moment correlation coefficient was used to assess the degree of association between continuous variables. The intra- and intertest limits of agreement between distance values at the end of the walk tests were investigated by plotting the individual differences against their means (Bland-Altman analysis). Heteroscedasticity was examined by plotting the absolute differences against individual means and calculating Spearman's correlation coefficient (17). If the correlation was close to zero, the mean bias and 95% limits of agreement were calculated as mean $\pm$ 1.96 SD of the between-estimated differences. On the other hand, if heteroscedasticity was suspected, data were transformed by taking natural logarithms from both methods. The mean biases $\pm$ 1.96 SD were first calculated on a logarithmic scale; after taking antilogs, these values were expressed on ratio scale (six-minute walk test/incremental shuttle walk test). Considering that adding and subtracting on the natural scale corresponds to multiplying and dividing in the logarithmic scale, the mean bias was multiplied and divided by the error ratio to add and subtract 1.96 SD (17).

A receiver operating characteristic curve was used to compare the accuracy of the two tests in predicting a severely reduced peak VO_2 (14 mL/kg/min or lower) and to identify the test cut-off with the best combination of sensitivity and specificity for that prediction. Event-free survival was analyzed by means of a Kaplan-Meier curve,

TABLE 2
Physiological and perceptual responses to the maximum incremental cardiopulmonary exercise test, the six-minute walk test and the incremental shuttle walk test

Cardiopulmonary exercise test	
Peak oxygen consumption, mL/kg/min	16.8±5.8
Anaerobic threshold, mL/kg/min	13.1±4.6
Respiratory exchange ratio	1.1±0.1
Peak heart rate, beats/min	126±23
Peak systolic blood pressure, mmHg	138±34
Peak diastolic blood pressure, mmHg	81±17
Perceived exertion (Borg score)	17±2
Six-minute walk test	
Peak heart rate, beats/min	113±17
Peak systolic blood pressure, mmHg	105±25
Peak diastolic blood pressure, mmHg	69±11
Perceived exertion (Borg score)	12±2
Distance walked, m	491±94
Distance walked, % predicted	88.3±15.7
Incremental shuttle walk test	
Peak heart rate, beats/min	117±17
Peak systolic blood pressure, mmHg	107±21
Peak diastolic blood pressure, mmHg	69±12
Perceived exertion (Borg score)	14±2*
Distance walked, m	422±119**
Speed, m/s	1.6±0.2

Values are presented as mean ± SD. * $P<0.05$ and ** $P<0.001$ for differences between six-minute walk test and incremental shuttle walk test

Figure 1 A Bland-Altman analysis of the within-test differences on the distance walked: note that the mean bias ±95% CI were almost identical between the six-minute walk test (6 MWT) and the incremental shuttle walk test (ISWT) (7 ± 40 m and 8 ± 45 m, respectively)

with the Wilcoxon test (Breslow) for post hoc analysis. The probability of a type I error was established to be 5% for all tests ($P<0.05$).

RESULTS

Intratest repeatability

There were no statistically significant differences in mean values of distance walked between the two consecutive incremental shuttle walk tests and the two six-minute walk tests (Table 2). The Bland-Altman analysis revealed a homoscedastic distribution of the intratest differences in distance walked for both tests. The mean bias was close to zero and the 95% CI of the differences were similarly narrow (7 ± 40 m and 8 ± 45 m for the six-minute walk test and the incremental shuttle walk test, respectively) (Figure 1).

Incremental shuttle test versus six-minute walk test

All patients were able to successfully complete the proposed walk tests. There were no clinically significant changes in the ST segment

Figure 2 The negative correlation between six-minute walk test (6 MWT)-incremental shuttle walk test (ISWT) differences on distance and the average walked distance (A). B Mean bias ±95% CI of the differences was expressed on a ratio scale (1.21 ± 0.39)

or chest pain; complex ventricular arrhythmias (nonsustained ventricular tachycardia) were found in three patients during the six-minute walk test and in one patient during the incremental shuttle walk test. Isolated ectopic ventricular beats were found in 21 patients; the occurrence of these abnormalities was similar in both tests.

On average, patients presented with well-preserved functional capacity as determined by the six-minute walk test: mean values were above the lower limit of normality in 90.4% of patients (57 of 63). There were statistically significant differences in distance walked between the six-minute walk test and the incremental shuttle walk test (491 ± 94 m versus 422 ± 119 m; $P<0.001$). However, the Bland-Altman analysis revealed that there was also a significant degree of heteroscedasticity on the distribution of these differences (see 'Methods' section); that is, the more impaired the patient, the higher the six-minute walk test-incremental shuttle walk test difference (Figure 2A). Therefore, the mean bias and the 95% CI of between-method differences in distance walked were expressed as ratios; patients walked, on average, $21\pm39\%$ more in the six-minute walk test than in the incremental shuttle walk test (Figure 2B).

Walk test versus cardiopulmonary exercise test

Symptom-limited maximal exercise capacity was only moderately reduced (Table 2); only 23 patients presented with a severely reduced peak VO_2 (14 mL/kg/min or lower). According to Weber's classification (18), 49.2% of subjects (31 patients) were considered to be in

Figure 3) The significant relationship between the distance walked in the six-minute walk test (6 MWT) and the incremental shuttle walk test (ISWT) versus peak oxygen consumption (VO_2). Note, however, the wide variability of distance at a given value of peak VO_2 (14 mL/kg/min) in either test

Figure 4) A receiver operating characteristic (ROC) curve of walk test performance in predicting a severely reduced peak oxygen consumption (14 mL/kg/min or lower). There was no significant between-test difference in the area under the curve ($P>0.05$). 6 MWT Six-minute walk test; ISWT Incremental shuttle walk test

class A or B (ie, peak VO_2 16 mL/kg/min or higher), 27 patients were in class C (10 mL/kg/min to 16 mL/kg/min), three subjects were in class D (6 mL/kg/min to 10 mL/kg/min) and only one patient was in class E (less than 6 mL/kg/min). Similarly, the mean anaerobic threshold was not severely reduced, with a mean value of 13.1 mL/kg/min (anaerobic threshold class B, Table 2).

Although there were highly significant correlations between peak VO_2 and distances walked in both tests ($r=0.76$ and $r=0.79$ for the six-minute walk test and the incremental shuttle walk test, respectively), distance walked varied widely for a given value of peak VO_2 (Figure 3). The area under the receiver operating characteristic curve for peak VO_2 prediction was remarkably similar between the two tests (Figure 4). According to the incremental shuttle walk test and the six-minute walk test, the best cut-offs for sensitivity and specificity of distance to predict a severely reduced peak VO_2 (14 mL/kg/min or lower) were 380 m (90% and 87%) and 490 m (83% and 83%), respectively.

Survival analysis

Patients were followed-up for a mean of 14 ± 8 months; 26 cardiovascular events were observed during this period (10 hospitalizations,

Figure 5) The event-free Kaplan-Meier survival curve according to peak oxygen consumption (VO_2) (A), and the distance walked on the six-minute walk test (6 MWT) and the incremental shuttle walk test (ISWT) (B and C, respectively). Walked distance cut-offs were based on individual test performance against peak VO_2 (see Figure 4). Note, however, that statistically significant differences were found only for peak VO_2 . Peak VO_2 : ≤ 14 mL/kg/min versus >14 mL/kg/min; 6 MWT ≤ 490 m versus >490 m; ISWT: ≤ 380 m versus >380 m. NS Not significant

14 deaths and two heart transplants). In line with previously published data, a peak VO_2 of 14 mL/kg/min or lower was associated with worsening prognosis (Figure 5A). In contrast, the investigators were unable to find a significant prognostic value of either the six-minute walk test (distance 490 m) or the incremental shuttle walk test (distance 380 m or less) (54.5% versus 40% and 60% versus 37.8%, respectively; $P>0.05$) (Figures 5B and 5C).

DISCUSSION

The results of the present investigation indicate that the incremental shuttle walk test is equivalent to the six-minute walk test in terms of safety, repeatability and accuracy in predicting a severely reduced peak VO_2 in a group of CHF patients with well-preserved functional capacity. However, peak VO_2 , but not the distance walked in either test, was

a good predictor of event-free survival. These data indicate that either the incremental shuttle walk test or the six-minute walk test can be useful to obtain a safe and inexpensive index of patient functional capacity. Direct measurement of peak VO_2 (incremental cardiopulmonary exercise test), however, remains the preferred procedure to predict survival in this patient population.

The present study has some important differences in relation to previously published data about the walk tests in CHF patients (2-5,9-14). This seems to be the first study to continuously follow the cardiac rhythm during the incremental shuttle walk test; as cited in the 'Results' section, the test was as safe as the six-minute walk test, despite its incremental nature. This is also the largest sample of CHF patients that has ever been prospectively submitted to the incremental shuttle walk test. Our data confirm the high level of reproducibility of the distance walked that was previously reported in smaller groups (11-14). Of importance, however, these previous studies failed to test for residuals heteroscedasticity of the between-test differences on walking distance. As shown in Figure 2A, the more disabled the patient, the less he or she walked in the incremental shuttle walk test compared with the six-minute walk test. We interpreted these results as evidence of the relative incapacity of the more severe patients to maintain the desired speed with test progression. These results indicate the need for future studies to evaluate whether the incremental shuttle walk test has the potential to underestimate the functional capacity of more disabled patients – exactly those patients in whom the test would be clinically more useful.

A particularly interesting feature of the present study was the inability of the walking tests to predict event-free survival (Figures 5B and 5C), despite their reasonably good accuracy in estimating peak VO_2 (Figure 4), a variable which, in turn, was a strong predictor of survival (Figure 5A). How to reconcile these rather opposite findings? In this context, an appreciation of Figure 3 can be informative. Although the overall sensitivity and specificity of the individual tests in predicting peak VO_2 was high, there was a wide

variability in walking distance at the same peak VO_2 . In addition, our patients walked more, on average, than patients evaluated in previous studies (2-5,9-14). Several hypotheses can be raised to explain this finding: patients evaluated in the present study might have presented with more preserved peripheral muscle mass (19), they might have been more encouraged during the tests (20) and, in particular, they might have been better 'trained'.

The present study presents some important limitations. First, the prognostic value of the walking tests could have been underestimated in this small sample. However, peak VO_2 was a good predictor even in this relatively short time frame (Figure 5A). Second, as mentioned, our results could be extrapolated only for patients who presented, on average, with a well-preserved functional capacity. Future studies should determine whether our results are also applicable to an older and more severely disabled population, especially those patients with worsening health status. In fact, we cannot rule out that test performance would not differ significantly in a larger and more heterogeneous group of patients. In addition, the issues of reproducibility (ie, day-to-day variation), the clinical value of the endurance shuttle walk test in chronic heart failure (21) and the sensitivity of the incremental shuttle walk test to interventions were not addressed in the present study.

CONCLUSIONS

The incremental shuttle walk test showed a similar test-retest repeatability and accuracy in estimating peak VO_2 to the six-minute walk test in patients with symptomatic CHF. Direct measurement of peak VO_2 , however, remains superior to either walking test in predicting survival – at least in patients with well-preserved functional capacity.

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