Incremental shuttle walk test in the assessment of patients for heart transplantation

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Abstract

Objective—To compare the incremental shuttle walk test (ISWT) with treadmill exercise testing (TT) derived measurement of peak oxygen consumption (peak Vo_2) in patients undergoing assessment for cardiac transplantation.

Design—Prospective comparison. All investigations occurred during a single period of admission for transplant assessment.

Setting—Single UK cardiothoracic transplantation unit.

Patients—25 patients recruited (21 men). Mean age was 53 years.

Interventions—Patients underwent two TT of peak Vo_2 using the modified Naughton protocol and three (one practice) ISWT. Investigations were performed on consecutive days.

Main outcome measures—Main outcome measures were repeatability of TT and ISWT assessments; relation between peak Vo_2 and distance walked in the ISWT; and receiver operating characteristic (ROC) analysis to establish a distance walked in the ISWT that predicted which patients would have a peak Vo_2 greater than 14 ml/min/kg.

Results—Both the ISWT and the TT were highly reproducible. Following the first practice walk, mean (SD) ISWT distances were 400.0 (146) m (ISWT2) and 401.3 (129) m (ISWT3), $r = 0.90$, $p < 0.0001$. Mean peak Vo_2 by TT was 15.2 (4.4) ml/kg/min (TT1) and 15.0 (4.4) ml/kg/min (TT2), $r = 0.83$, $p < 0.0001$. The results revealed a strong correlation between distance covered in the ISWT and peak Vo_2 obtained during TT ($r = 0.73$, $p = 0.0001$). ROC analysis showed that a distance walked of 450 m allowed the selection of patients with a peak Vo_2 of over 14 ml/min/kg.

Conclusions—This work confirms the utility of the ISWT in the assessment of exercise capacity in patients with severe heart failure undergoing assessment for cardiac transplantation. ISWT may provide a widely applicable surrogate measure for peak Vo_2 estimation in this population. Shuttle distance walked may therefore allow the convenient, serial assessment of patients with heart failure before referral for transplantation.

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Keywords: incremental shuttle walk; peak oxygen consumption; cardiac transplantation

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Cardiac transplantation is an effective treatment for severe heart failure improving both quality and quantity of life.[1] Unfortunately, donor organ scarcity means that only a small fraction of patients with heart failure can be offered transplantation. The selection of appropriate patients is difficult because many of the features of heart failure such as left ventricular function are only weakly related to symptoms and are poor prognostic discriminators. Of the available methods for assessing prognosis in heart failure, the assessment of exercise capacity by measurement of maximal oxygen consumption (peak Vo_2) during treadmill or cycle ergometer exercise testing is perhaps the most useful and widely used. It provides an accurate and reproducible measure of both symptomatic status and prognosis in patients with heart failure[2 3] and when combined with other outcome predictors allows accurate outcome estimation.[4] Unfortunately, the equipment is expensive and not widely available outside large institutions. In addition, the test is limited in its application, firstly by the need for an incremental exercise protocol, which is an abnormal exercise that many patients find difficult; secondly, by the required facemask or mouthpiece, which may be poorly tolerated; and finally, by the need for staff skilled in both exercise physiology and in patient motivation techniques to obtain meaningful results.

Thus, there is a clear requirement for an alternative inexpensive and simple measure of exercise capacity that is reproducible and prognostically reliable.

The incremental shuttle walk test (ISWT) was originally developed to assess patients with chronic obstructive pulmonary disease and requires patients to walk at a gradually increasing speed until they reach a symptom limited maximum.[5] Furthermore, a clear relation has been shown in patients with chronic obstructive pulmonary disease between distance walked in the ISWT and peak Vo_2.[6] The wide range of walking speed in the ISWT allows the accommodation of all ambulant patients, from those with minimal disability to those with more severe symptoms.

We report a prospective comparison of the ISWT with the measurement of Vo_2 peak during treadmill exercise testing (TT) in 25 patients undergoing assessment for cardiac transplantation at our institution. We first sought to establish the reproducibility of each test and subsequently examined their relation.

Table 1 Patient characteristics for the entire group and for the two groups established by dividing the patient population into those with (group 2) and those without (group 1) peak oxygen consumption > 14 ml/min/kg

	Total group (n=25)	*Group 1 (n=8)*	*Group 2 (n=17)*	*p Value*
Male (%)	84	87.5	82.4	0.67
Age (years)	53 (8)	51 (12)	54 (6)	0.35
LVEF (%)	27.8 (12.2)	26.3 (18.3)	28.5 (8.7)	0.67
LVEDD (cm)	6.6 (1.2)	6.9 (1.0)	6.4 (1.3)	0.5
Cardiac index (l/min/m^2)	2.2 (0.5)	1.8 (0.36)	2.4 (0.39)	0.03
Serum sodium (mmol/l)	138 (3.7)	137.8 (3.5)	137.8 (3.9)	0.98
NYHA	II–III	III–IV	II–III	0.0005
PCWP (mm Hg)	17.2 (10.5)	22.2 (8.7)	14.6 (10.6)	0.11
TPG (mm Hg)	7.3 (2.2)	7.2 (1.06)	7.4 (2.6)	0.78
Shuttle distance (m)	401 (147)	287 (127)	454 (124)	0.0005
V_{O_2} (ml/min/kg)	15.2 (4.4)	10.0 (2.0)	17.6 (2.7)	–

Data are mean (SD). p Values for comparison group 1 versus group 2.
LVEDD, left ventricular end diastolic dimension; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association functional class; PCWP, pulmonary capillary wedge pressure; TPG, transpulmonary gradient; V_{O_2}, peak oxygen consumption.

Patients and methods

PATIENTS

Patients undergoing assessment for cardiac transplantation were recruited between January and September 1999. All ambulatory patients were invited to take part but patients requiring inotropic support were excluded. All patients underwent an initial treadmill assessment for measurement of peak V_{O_2} using a modified Naughton protocol as part of the routine assessment process. Patients unable to complete a single two minute stage (11 patients) were excluded. Twenty five (21 men) of 48 eligible patients assessed during this period consented to take part in this study. The study was approved by the local research ethics committee and written consent was obtained from all patients. The mean age was 53 years (range 33–69 years). Fifteen of the 25 patients had a diagnosis of ischaemic cardiomyopathy and 10 had a dilated non-ischaemic cardiomyopathy.

STUDY DESIGN

All investigations occurred during a single period of admission for transplant assessment according to the following schedule: day 1, 9 am TT (TT1), 4 pm ISWT twice (one practice (ISWT1), one formal assessment (ISWT2)); day 2, 2 pm ISWT once (ISWT3); day 3, 11 am TT (TT2). The timings of tests had to be adjusted, on occasion, to accommodate other transplantation assessment investigations. All medications were continued as routine. Patients who used sublingual nitrates were given one dose five minutes before each test.

SHUTTLE WALKING TEST

The patients performed three ISWT.[5] The design of the test was as follows: the patients were required to walk up and down a 10 m course at a speed dictated by signals from an audio tape recorder. The walking speed was increased by a small increment at 1 minute intervals. The test was terminated either by the patient if he or she felt too breathless to continue at the desired speed or by the operators if the patient failed to complete a 10 m length (shuttle) in the time allowed. During the test, heart rate was recorded with a Polar heart rate monitor.

TREADMILL PROTOCOL

Patients were subjected to an incremental TT using the modified Naughton protocol, which increases in two minute stages. Exercise was discontinued when the patient was unable to maintain the imposed workload (manifest by the inability to maintain speed consistently on the treadmill, or by development of significant exercise induced chest pain or ECG disturbance). Patients breathed through a two way non-rebreathable valve supported by headgear supplied for use with the treadmill. Inspired ventilation was monitored continuously by a Fleish pneumatograph positioned at the inspiratory port of the two way mouthpiece valve. Expired gas was passed through a mixing chamber, and fractional O_2 and CO_2 were recorded continuously by rapid response analysers (Zirconia cell analyser and Infra red rapid response analyser, for O_2 and CO_2 respectively, Morgan Medical Ltd, Kent, UK). Peak V_{O_2} and CO_2 output were calculated at 30 second intervals throughout the test. Peak V_{O_2} was defined as the maximal rate of O_2 consumption in ml/min/kg. Anaerobic threshold was defined to have occurred when there was a systematic increase in the ventilatory equivalent of O_2 with a corresponding increase in CO_2 output. Patients stopped because of shortness of breath (50%), limb fatigue (20%), and chest pain (30%). Reasons for stopping the ISWT and TT were identical for each patient for each test.

PATIENT PREFERENCE

Patient preference was determined by the responses to a questionnaire administered by a technician.

STATISTICAL ANALYSIS

All statistical analysis was performed on a standard personal computer running the ARCUS software package (Addison Wesley Longman, Cambridge, UK). Continuous variables were assessed for normal distribution and compared by the two way unpaired *t* test. Receiver operating characteristic (ROC) analysis was performed using the methodology of Altman.[7] Regression and correlation analysis was performed as described by Bland and Altman.[8] Values are presented as mean (SD) unless otherwise stated. Significance was assumed when $p < 0.05$.

Results

Clinical and haemodynamic variables for the patients are shown in table 1. During TT only three of the 25 patients achieved anaerobic threshold, despite firm encouragement. All of these patients reached anaerobic threshold on both TT V_{O_2} estimations. The mean respiratory exchange ratio for all patients was 0.95 (0.12).

REPRODUCIBILITY

Both the ISWT and the TT were highly reproducible (fig 1 and 2). Following the first practice walk (347 (140) m), mean ISWT distances were 400.0 (146) m (ISWT2) and 401.3

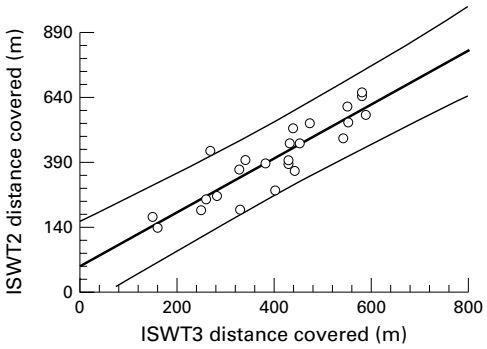


Figure 1 Distance walked by each patient (m) in incremental shuttle walk test 2 (ISWT2) v test 3 (ISWT3) ($r = 0.90$, $p < 0.0001$). The 95% prediction interval is shown.

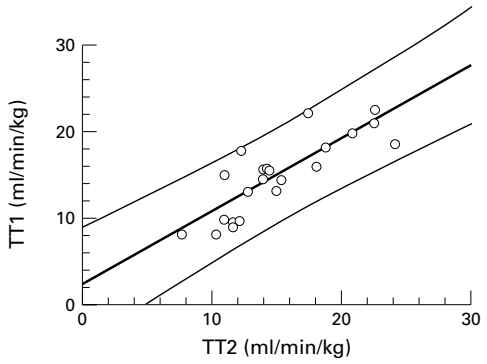


Figure 2 Peak oxygen consumption (ml/min/kg) achieved in treadmill test 1 (TT1) v treadmill test 2 (TT2) ($r = 0.83$, $p < 0.0001$). The 95% prediction interval is shown.

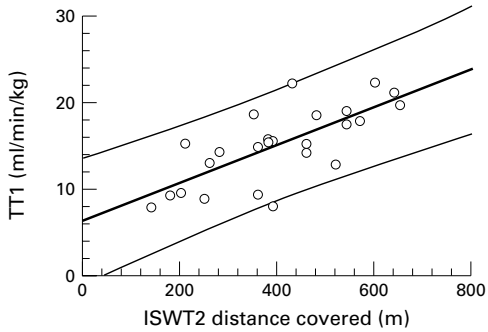
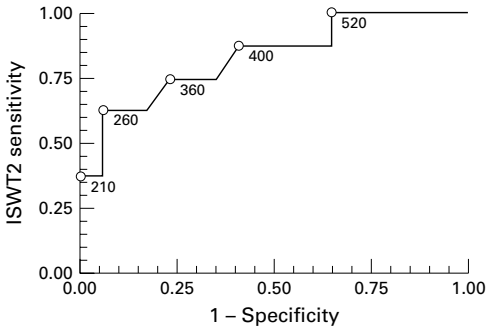


Figure 3 Distance walked in incremental shuttle walk test 2 (ISWT2) (m) v peak oxygen consumption (ml/min/kg) achieved in treadmill test 1 (TT1) ($r = 0.73$, $p = 0.0001$). The 95% prediction interval is shown.

(129) m (ISWT3), $r = 0.90$, $p < 0.0001$. Mean Vo_2 by TT was 15.2 (4.4) ml/kg/min (TT1) and 15.0 (4.4) ml/kg/min (TT2), r = 0.83, $p < 0.0001$.

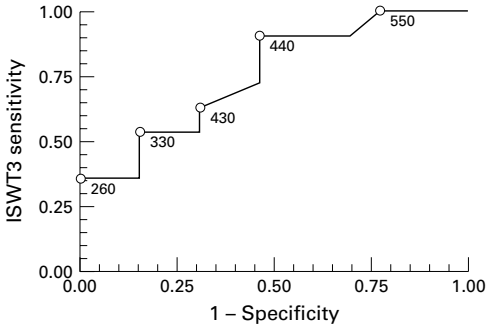
RELATION BETWEEN PEAK VO_2 AND ISWT DISTANCE

The results revealed a strong correlation between distance covered in the ISWT and peak Vo_2 obtained during the TT (fig 3). This is represented by the regression equation $Vo_2 = 0.022 \times \text{Dist} + 6.4$, where Vo_2 is peak Vo_2 (ml/min/kg) and Dist is distance walked during the ISWT (m) ($r = 0.73$, p = 0.0001). Mean peak heart rates for both tests were similar (Vo_2, 128 (25) beats/min; ISWT, 129 (23) beats/min, $r = 0.68$, p = 0.0004).



Cut off (m)	210	260	360	400	520
Sensitivity	0.38	0.63	0.75	0.88	1
Specificity	1	0.94	0.77	0.59	0.35

Figure 4 Receiver operating characteristic plot for peak oxygen consumption > 14 ml/min/kg comparing incremental shuttle walk test 2 (ISWT2) with treadmill test 1 (TT1).



Cut off (m)	260	330	430	440	550
Sensitivity	0.23	0.54	0.69	0.85	1.0
Specificity	1.0	0.9	0.64	0.55	0.36

Figure 5 Receiver operating characteristic plot for peak oxygen consumption > 14 ml/min/kg comparing incremental shuttle walk test 3 (ISWT3) with treadmill test 2 (TT2).

Of the other variables routinely measured at cardiac transplantation assessment (table 1), only resting cardiac index correlated with peak Vo_2 and shuttle distance ($r = 0.58$, p = 0.005 and $r = 0.43$, p = 0.05, respectively) on simple linear regression. Backwards stepwise multiple linear regression, of the variables listed in table 1, identified only distance covered in the ISWT as a predictor of peak Vo_2 (p = 0.04).

DISCRIMINATING POWER

To assess the ability of the ISWT to discriminate between patients with a peak Vo_2 of less than or greater than 14 ml/min/kg, ROC curves were constructed (fig 4, ISWT2 and TT1, and fig 5, ISWT3 and TT2). The data are presented separately to avoid bias resulting from the correlation of data sets. The two curves show that the ISWT threshold providing optimal sensitivity and specificity is not precisely determined by a single comparison. From the ROC curves, it appears that an ISWT threshold of between 370 and 430 m provides sensitivities and specificities of approximately 75% for predicting which patients have a mean peak Vo_2 of over 14 ml/min/kg.

ISWT AND PROGNOSTIC INDICES OF HEART FAILURE

The mean peak Vo_2 was 15.2 (4.4) ml/min/kg. On the basis of previous work,[2] we divided the patients into two groups: group 1, with a Vo_2 of $\leq$ 14 ml/min/kg; and group 2, with a Vo_2 of > 14 ml/min/kg. Of all variables measured, New York Heart Association (NYHA) functional class and resting cardiac index were statistically different between groups. In addition, the distance covered in the ISWT was highly significantly different between group 1 and group 2.

Both pulmonary capillary wedge pressure ($p = 0.03$) and NYHA functional class ($p = 0.02$) were significantly different between patients who could walk further than 450 m and those who managed 450 m or less.

PATIENT PREFERENCE

Twenty four of the 25 patients stated that they preferred the shuttle walk test.

Discussion

This study has shown that the ISWT appears to provide a reliable and reproducible measure of exercise tolerance in severe heart failure. The close correlation of ISWT distance with peak Vo_2 indicates that the results may be useful as a prognostic index in patients with heart failure. ROC analysis shows that an ISWT distance of 450 m is a good discriminator of patients with a Vo_2 of more than 14 ml/min/kg.[9] This peak Vo_2 is widely considered to be an important indicator of prognosis in assessment for cardiac transplantation; patients with values below this level have a high short term mortality.[2 3 10]

Advantages of the ISWT over the conventional TT Vo_2 assessment include better patient tolerance, ease of administration, and no requirement for expensive equipment. However, as with all tests of exercise tolerance, it is subject to variations in patient motivation and the investigators' ability to ensure that patients reach their symptomatic limits. The test appears to have wide applicability. Recent work has shown that the ISWT can be used as a reproducible measure of exercise capability[5 11] and is comparable with peak Vo_2 in patients with lung disease.[6] Similar results have been reported in patients with cardiac pacemakers.[12]

Two previous studies have compared the ISWT with peak Vo_2 exercise testing in patients with heart failure. In patients undergoing assessment at a heart failure clinic, Vo_2max and ISWT distance covered showed a good correlation ($r = 0.84$, $p < 0.0001$) in a population of 50 patients with mild to moderate heart failure (mean Vo_2 17.9 (6.1) ml/kg/min).[13] In a study comparing cycle ergometer derived peak Vo_2 with the six minute walk test and the ISWT, Morales and colleagues[14] also showed a close ($r = 0.83$) correlation between Vo_2 and ISWT distance covered in patients with moderate heart failure (mean Vo_2 17.8 (4.4) ml/kg/min). As in our study they found that the ISWT was reproducible after just one walk. However, the mean peak Vo_2 in both of these studies was significantly higher than that of our patients, suggesting less severe heart failure. In addition, the use of a cycle ergometer rather than a treadmill may underestimate peak Vo_2.[15] Although the patients studied by Morales and colleagues[14] had less severe heart failure than our study group, a cut off distance of 450 m also defined the patients with a Vo_2 of > 14 ml/kg/min. Again, the ISWT result was the only predictor of peak Vo_2 by multiple regression.

Our work confirms the utility of the ISWT in the assessment of exercise capacity in patients with severe heart failure undergoing assessment for cardiac transplantation. In addition ISWT may provide a widely applicable surrogate for peak Vo_2 estimation in this population. The shuttle walk test gives an incremental workload provoking maximal performance in the same way as a conventional TT. Further large scale studies are required, but if our results are confirmed, shuttle distance walked may allow the convenient, serial assessment of patients with heart failure before referral for transplantation.

STUDY LIMITATIONS

Unfortunately only a small number of patients reached an anaerobic threshold during formal TT. Patients with severe heart failure often have oscillatory or sustained hyperventilation. This results in excess CO_2 elimination from the onset of exercise.[16] This makes the non-invasive determination of anaerobic threshold difficult in these patients. In addition, a number of our patients with ischaemic cardiomyopathy terminated their exercise because of angina.[6] Despite this limitation, the exercise workload in the TT and ISWT appear to be comparable because maximal heart rates were similar (75% and 77% predicted maximum, respectively). Moreover, recent work has shown that the prognostic power of a low peak Vo_2 in patients with severe heart failure is maintained even when anaerobic threshold is not reached.[17]

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IMAGES IN CARDIOLOGY

Coronary artery rupture treated with microcoil occlusion

Coronary artery rupture is a rare complication of balloon angioplasty. Techniques used in its management include emergency surgery, covered stent deployment, and microcoil vessel occlusion. The latter has been reported twice. We report a further case of successful coil occlusion of a ruptured coronary artery following angioplasty.

A 53 year old man presented with unstable angina. Angiography demonstrated occlusion of the first obtuse marginal artery. Balloon angioplasty using a 2 mm balloon was undertaken with deployment of a 2.5 × 18 mm stent (S670, Medtronic).

Shortly after stent deployment, the patient became haemodynamically compromised and angiography showed perforation of the obtuse marginal artery distal to the stent site (below left).

The pericardium was drained percutaneously. The patient continued to haemorrhage at a rate of 50 ml/min into the pericardium. Covered stent deployment was not considered feasible because of the calibre of the distal vessel at the site of perforation. Coil occlusion of the obtuse marginal artery was therefore performed, using six 2 × 10 mm and two 2 × 5 mm fibred platinum coils (Target Therapeutics) (below right). There was no further extravasation on contrast injection and no further blood was aspirated from the pericardium. The patient sustained a rise in creatinine kinase to a peak of 444 IU/l, but otherwise made an excellent recovery and was discharged one week later.

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