



An official European Respiratory Society/ American Thoracic Society technical standard: field walking tests in chronic respiratory disease

Anne E. Holland, Martijn A. Spruit, Thierry Troosters, Milo A. Puhan, Véronique Pepin, Didier Saey, Meredith C. McCormack, Brian W. Carlin, Frank C. Sciurba, Fabio Pitta, Jack Wanger, Neil MacIntyre, David A. Kaminsky, Bruce H. Culver, Susan M. Revill, Nidia A. Hernandez, Vasileios Andrianopoulos, Carlos Augusto Camillo, Katy E. Mitchell, Annemarie L. Lee, Catherine J. Hill and Sally J. Singh

Affiliations: For a full list of the authors' affiliations please refer to the Acknowledgements.

Correspondence: Anne E. Holland, La Trobe University Clinical School, Alfred Health, Level 4, The Alfred Centre, 99 Commercial Rd, Melbourne 3004, Australia. E-mail: a.holland@alfred.org.au

ABSTRACT Field walking tests are commonly employed to evaluate exercise capacity, assess prognosis and evaluate treatment response in chronic respiratory diseases. In recent years, there has been a wealth of new literature pertinent to the conduct of the 6-min walk test (6MWT), and a growing evidence base describing the incremental and endurance shuttle walk tests (ISWT and ESWT, respectively). The aim of this document is to describe the standard operating procedures for the 6MWT, ISWT and ESWT, which can be consistently employed by clinicians and researchers.

The Technical Standard was developed by a multidisciplinary and international group of clinicians and researchers with expertise in the application of field walking tests. The procedures are underpinned by a concurrent systematic review of literature relevant to measurement properties and test conduct in adults with chronic respiratory disease.

Current data confirm that the 6MWT, ISWT and ESWT are valid, reliable and responsive to change with some interventions. However, results are sensitive to small changes in methodology. It is important that two tests are conducted for the 6MWT and ISWT.

This Technical Standard for field walking tests reflects current evidence regarding procedures that should be used to achieve robust results.



@ERSpublications

Technical Standard document: standard operating procedures for the 6MWT, ISWT and ESWT in chronic respiratory disease <http://ow.ly/Bq2B9>

This article has supplementary material available from erj.ersjournals.com

Received: Aug 16 2014 | Accepted: Aug 31 2014 | First published online: Oct 30 2014

Support statement: The realisation of this Technical Standard would not have been possible without the financial support of the European Respiratory Society and American Thoracic Society. Sally J. Singh is supported by the National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care East Midlands (CLAHRC EM), and work took place at the University Hospitals of Leicester NHS Trust. Support was also provided by the NIHR Leicester Respiratory Biomedical Research Unit. The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Dept of Health.

Conflict of interest: Disclosures can be found alongside the online version of this article at erj.ersjournals.com

Copyright ©ERS 2014

Overview

The aim of this Technical Standard is to document the standard operating procedures for the 6-min walk test (6MWT), incremental shuttle walk test (ISWT) and endurance shuttle walk test (ESWT) in adults with chronic respiratory disease. The testing procedures were developed by a multinational and multidisciplinary group of experts in field exercise testing, informed by a systematic review of the measurement properties and interpretation of the 6MWT, ISWT and ESWT in adults with chronic respiratory disease [1].

The key findings of the Technical Standard are as follows.

- 1) The 6-min walking distance (6MWD), ISWT and ESWT demonstrate good construct validity. Strong relationships with measures of exercise performance and physical activity support their conceptualisation as tests of functional exercise performance.
- 2) A lower 6MWD is strongly associated with increased risk of hospitalisation and mortality in people with chronic respiratory disease, with a small number of studies suggesting a similar relationship for the ISWT.
- 3) The 6MWD, ISWT and ESWT exhibit good test–retest reliability; however, there is strong evidence of a learning effect for the 6MWT and ISWT. Two tests should be performed when the 6MWT or ISWT are used to measure change over time.
- 4) The 6MWD, ISWT and ESWT are responsive to treatment effects in people with chronic respiratory disease; however, most studies have evaluated responsiveness to rehabilitation and fewer data are available to confirm responsiveness to other interventions.
- 5) The 6MWD and ISWT elicit a peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) that is similar to that during a cardiopulmonary exercise test (CPET). As a result, the contraindications and precautions for field testing should be consistent with those used for a CPET.
- 6) The 6MWD is very sensitive to variations in methodology, including use of encouragement, provision of supplemental oxygen, changes in track layout and length, and use of wheeled walkers. These factors should be held constant on repeat testing.
- 7) The 6MWD is the primary outcome of the 6MWT.
- 8) The lowest arterial oxygen saturation measured by pulse oximetry (SpO_2) recorded during a 6MWT has emerged as an important marker of disease severity and prognosis; however, it may not be consistent with end-test SpO_2 . Continuous pulse oximetry is recommended during the 6MWT, to ensure that the lowest SpO_2 is recorded.
- 9) Available evidence suggests a minimal important difference (MID) of 30 m for the 6MWD in adults with chronic respiratory disease.
- 10) The primary outcome of the ISWT is distance, measured to the nearest 10 m.
- 11) The primary outcome of the ESWT is time, although distance has also been reported.
- 12) Application of reference equations for 6MWD or ISWT to an individual gives rise to substantial variation in predicted values. If reference values are to be used, an equation generated and verified in a local population should be applied where possible.
- 13) Testing procedures that are consistent across the 6MWT, ISWT and ESWT include test location and staffing, patient assessment and preparation, use of oxygen and medications, indications for test cessation, and quality assurance. These procedures are detailed in the Technical Standard.

Introduction

The 6MWT plays a key role in evaluating functional exercise capacity, assessing prognosis and evaluating response to treatment across a wide range of respiratory diseases. Since publication of the previous American Thoracic Society (ATS) statement on the 6MWT in 2002 [2], new information regarding the 6MWT has emerged in a range of areas, including methods of test performance and interpretation. This increased body of knowledge has significant implications for the good conduct of the 6MWT in individuals with chronic respiratory disease, in both research and clinical settings.

The last 10 years have also seen a growing body of evidence describing the uses and measurement properties of the ISWT and the ESWT. Given the increasing uptake of these field tests in clinical practice, the scope of the 2002 document has been expanded to include the ISWT and ESWT. While the use of other field tests has also been reported in chronic respiratory disease (*e.g.* timed up and go, sit to stand test, 4-m gait speed test), the committee considered that there were currently insufficient data to include them in this version of the Technical Standard.

The testing procedures outlined in this document are based on a systematic review of the literature describing the use and properties of these field walking tests in adults with chronic respiratory disease, including chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), cystic fibrosis (CF), bronchiectasis, asthma, pulmonary arterial hypertension (PAH) and pulmonary vascular disease [1]. As a consequence, these standards are not intended for application to children or to individuals who do not have chronic respiratory disease. This Technical Standard provides guidance on the practical aspects of conducting field walking tests in a safe, effective and reproducible manner. This document is not intended to provide guidance regarding when or in which patients these tests should be performed. The measurement properties of each field walking test are described individually. Standard operating procedures common to all three tests are outlined and those specific to each test are described. A brief comparison of the three tests is included. Finally, important differences between this document and the previous ATS statement on the 6MWT are highlighted.

Methods

An *ad hoc* Task Force was assembled to develop technical standards for the performance of the 6MWT, ISWT and ESWT based upon a systematic review of the evidence [1]. Co-chairs were selected by the Pulmonary Rehabilitation Assembly and Proficiency Standards Committee of the ATS and the Rehabilitation and Chronic Care Assembly and Allied Respiratory Professionals Assembly of the European Respiratory Society (ERS), then approved by the leadership of both societies. Members of the Task Force were selected by the co-chairs on the basis of their expertise in application of field walking tests in research and/or clinical practice. All potential conflicts of interest were disclosed and managed according to the policies and procedures for joint ATS/ERS projects. Drafts of this document were prepared by two members (Anne E. Holland and Sally J. Singh), with all authors providing comment and suggestions for the final document. The methods checklist is presented in [table 1](#).

The systematic review which informs this document addressed seven questions relevant to the measurement properties, performance, clinical utility, reporting, monitoring, reference equations and interpretation for field walking tests in chronic respiratory disease. Full details are provided in a companion paper [1].

The 6MWT: measurement properties important to test conduct

The 6MWT is a self-paced test of walking capacity. Patients are asked to walk as far as possible in 6 min along a flat corridor. The distance in metres is recorded. Standardised instructions and encouragement are commonly given during the test [2].

Validity of 6MWD

There is a large body of data demonstrating construct and criterion validity for the 6MWD in individuals with chronic respiratory disease [1]. Relationships are strongest with measures of maximal exercise

TABLE 1 Methods checklist

	Yes	No
Panel assembly		
Included experts for relevant clinical and nonclinical disciplines	X	
Included individual who represents the views of patients and society at large		X
Included methodologist with appropriate expertise	X	
Literature review		
Performed in collaboration with a librarian	X	
Searched multiple electronic databases	X	
Reviewed reference lists of retrieved studies	X	
Evidence synthesis		
Applied pre-specified inclusion and exclusion criteria	X	
Evaluated included studies for sources of bias	X	
Explicitly summarised benefits and harms	X	
Used PRISMA1 to report systematic review		X
Used GRADE to describe quality of evidence		X
Generation of recommendations		
Used GRADE to rate the strength of recommendations		NA

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; GRADE: Grading of Recommendations Assessment, Development and Evaluation; NA: not applicable.

performance and physical activity (correlation coefficients 0.4–0.93). Relationships between 6MWD and respiratory function (forced expiratory volume in 1 s (FEV₁), forced vital capacity and diffusing capacity of the lung for carbon monoxide (DLCO)) (correlation coefficients 0.31–0.55) or health-related quality of life (HRQoL) (correlation coefficients 0.03–0.65) are of weak to moderate strength across all disease groups examined.

Direct comparisons of the physiological demands of the 6MWT and CPET show that although measures of peak exercise performance ($\dot{V}O_{2,\text{peak}}$ and heart rate (HR) peak) are similar between the tests, the 6MWT has substantially lower ventilatory requirements (peak carbon dioxide production, peak ventilation and respiratory exchange ratio) [3–8], which may contribute to its tolerability in adults with chronic respiratory disease. Overall, these data lend support to the conceptualisation of the 6MWT as a test of functional exercise capacity.

Reliability and learning effect for 6MWD

The 6MWD is a reliable measure in people with chronic respiratory disease, with excellent intra-class correlation coefficients (ICCs) (range 0.82–0.99) [1]. There are no discernible differences in reliability across groups with different chronic respiratory diseases. Despite its excellent reliability, there is strong evidence of a learning effect for the 6MWD when two or more tests are conducted. 13 studies in patients with COPD show a pooled mean improvement on the second 6MWT of 26.3 m [1]. This estimate does not change when including only the subgroup of studies where the two tests are conducted within 24 h (26.1 m). The largest study to address this issue (n=1514) reported a 95% confidence interval for the learning effect of 24–29 m [9]. There is some variability across individuals: the proportion of participants who walked further on the second 6MWT ranged from 50% to 87% across studies. Fewer data are available in other chronic respiratory diseases, although the available studies tend to support a learning effect across all chronic respiratory diseases [1]. Whether the learning effect is equally significant for individuals who have previously performed multiple 6MWTs is difficult to establish, as few data are available. If the tests are repeated 3 months later, the learning effect appears to persist in individuals with COPD; however, it may be smaller in magnitude [10].

The effect of learning on the 6MWD is large enough to be clinically important when the 6MWT is used to evaluate response to treatment or change over time. In these situations, two 6MWTs should be performed and the best 6MWD recorded. Use of two 6MWDs may also decrease the sample size requirements for clinical trials, due to reduced variability in the pre- and post-intervention measures [11]. Where the 6MWD is used as a one-off measure to stage disease or assess risk (e.g. likelihood of hospitalisation or mortality), the magnitude of the learning effect may be less important and one test may be sufficient. However, clinicians should be mindful of the learning effect if the 6MWD is approaching pre-defined thresholds on which treatment decisions may be based [12, 13]; in this situation, repeat testing should be considered. One test may also be sufficient for patients who have recently performed the test, where the learning effect is smaller (e.g. end of pulmonary rehabilitation) [10].

Relationship of 6MWD to clinical outcomes

The 6MWD has a strong relationship to important clinical outcomes in individuals with chronic respiratory disease. A shorter 6MWD was associated with increased mortality in 13 (93%) out of the 14 COPD studies reviewed [1]. Associations were less consistent in ILD (four (50%) out of eight studies) and PAH (six (66%) out of nine studies) [1]. There is less evidence for the association of 6MWD with hospitalisation, but all studies in which it was evaluated (n=3, COPD and ILD) found a statistically significant relationship [1]. It was outside the scope of this document to identify thresholds for 6MWD to categorise patients according to their risk for these outcomes.

Methodological factors affecting test performance

The 6MWD is highly sensitive to changes in methodology (table 2). Given the impact of encouragement on 6MWD [33] and the use of encouraged tests in the generation of reference equations [1], it is recommended that standardised phrases of encouragement are used (see later section on the testing protocol for 6MWT). Provision of supplemental oxygen [26–29], method for carrying the supplemental oxygen [31, 32] and use of wheeled walkers [20–25] also have an important impact on 6MWD. These factors must be kept constant on repeat testing. The 6MWD generated using an externally paced treadmill is substantially lower than in a hallway [14, 15], which is probably the result of the poor walking efficiency during treadmill walking in subjects unaccustomed to this activity. Externally paced treadmill testing is not recommended. Track layout and length may also affect performance on the test, especially when very short track lengths are used [19]; these factors should be kept constant where within-subject comparison of 6MWD on subsequent occasions

TABLE 2 Effect of methodological variations on 6-min walking distance (6MWD)

Variation in methodology	Studies n	First author [ref.]	Effect on 6MWD
Hallway versus treadmill	2	STEVENS [14] DE ALMEIDA [15]	13–20% less on treadmill
Indoors versus outdoors	1	BROOKS [16]	4 m (1%) more outside
Circular versus straight track	2	BANSAL [17] SCIURBA [18]	13–19 m (3–5%) more on circular track
Track length	2	SCIURBA [18] BEEKMAN [19]	No statistically significant difference in 6MWD from tracks of 15–121 m 50 m more on 30-m track compared to 10-m track
Wheeled walking aid versus no aid	6	GUPTA [20] HONEYMAN [21] PROBST [22] ROOMI [23] SOLWAY [24] VAES [25]	Weighted mean 6.2% more with wheeled walker Range 2–46 m more with wheeled walker 83 m more with modern draisine compared to wheeled walker
With versus without oxygen	4	DAVIDSON [26] FUJIMOTO [27] ROOYACKERS [28] JOLLY [29]	12–59 m more with oxygen
Oxygen versus compressed air	2	JOLLY [29] MCDONALD [30]	17–109 m more with oxygen
Carry oxygen versus oxygen in wheeled cart	1	CRISAFULLI [31]	23 m more with wheeled cart
Patient carries oxygen versus tester carries oxygen	1	WOODCOCK [32]	24 m versus 35 m improvement
Encouragement	1	GUYATT [33]	30.5 m more with encouragement
Instructions	1	WEIR [34]	53 m further when asked to walk as “fast” as possible, rather than as “far” as possible

is required. For track lengths of >15 m, differences may be small enough such that tests on different track layouts can still be used for risk stratification [1]; however, more data are needed to confirm this.

Monitoring and reporting for 6MWT

Safety

Complications associated with the performance of the 6MWT are unusual. We were unable to find published reports of complications associated with performance of the 6MWT in clinical trials. Only two articles have specifically addressed the issue of complications during the 6MWT. In 741 patients attending an outpatient pulmonary rehabilitation programme who completed the 6MWT in accordance with a standardised protocol, including continuous monitoring of oxyhaemoglobin saturation (S_{pO_2}) and HR, adverse events were noted in 43 (6%) of patients [35]. The most common adverse event was oxygen desaturation <80%, upon which the test was terminated by the operator (35 out of 43); chest pain (one out of 43) and tachycardia (one out of 43) were also recorded. No long-term adverse sequelae from these events were reported. In the remaining tests the patients developed intolerable symptoms and the test was discontinued, which would be expected during the 6MWT and is not considered a complication. A second study in ILD (n=19) showed that desaturation to <80% occurred in 58% of participants during the 6MWT [36]. Concurrent ECG monitoring showed no clinically significant arrhythmias that needed treatment, although atrial tachycardia occurred in one case.

Measurements

The 6MWD is the primary outcome of the 6MWT, given its excellent reliability and validity, as well as its strong relationship to important clinical outcomes. The 6MWD should be reported for every test in metres or feet. However, other outcomes have been reported, such as S_{pO_2} , HR responses, symptoms of dyspnoea and fatigue and 6-min walk work (6MWD × body weight).

Oxyhaemoglobin saturation

Oxygen desaturation during a 6MWT provides information regarding exercise-induced desaturation, disease severity and disease progress. Exercise-induced desaturation is associated with impaired daily

physical activity, faster FEV₁ decline and worse prognosis [37, 38], which supports its clinical importance. The 6MWT is more sensitive for identifying exercise-induced desaturation than cycle testing [39]. Measurements of SpO₂ during the 6MWT are reliable [1], provided that an adequate pulse signal is obtained. However, change in SpO₂ may be more variable in people with systemic sclerosis-associated ILD (SSc-ILD) than in other lung conditions (ICCs ranging 0.24–0.64 in SSc-ILD, compared to 0.80–0.97 in CF and COPD) [1], perhaps due to cutaneous involvement in SSc-ILD. The 6MWT may be safe without continuous monitoring of SpO₂ [36]. However, constant monitoring of SpO₂ during the 6MWT is needed to obtain an accurate measure of exercise-induced desaturation, as the lowest SpO₂ often does not occur at the end of the test [40, 41].

A number of novel desaturation indices have been proposed in patients with ILD, with the aim of improving the ability of the 6MWT to predict mortality. These include the distance–saturation product [42–45], the desaturation area [46] and the desaturation–distance ratio [47]. As only a small number of studies are available, the utility of these measures has not been confirmed and they are not routinely collected during the 6MWT.

Heart rate

The resting and end-test HR are often recorded during the 6MWT. Limited data are available regarding the reliability of HR measures during the 6MWT; however, change in HR recorded on the pulse oximeter appears reliable (ICCs 0.62–0.87) [9, 48]. No studies have compared the HR obtained from pulse oximetry to that obtained with other methods (e.g. frequency meter). Other measures of HR response include HR recovery (HRR), which is the reduction in HR with rest that occurs after the 6MWT is concluded. A reduced HRR during the first minute after the 6MWT has been associated with poor outcomes, including increased mortality, in ILD [49] and PAH [50, 51]. However, there is not a universally accepted cut-off for HRR that is applicable across chronic respiratory diseases.

Dyspnoea

Dyspnoea may be an important determinant of the 6MWD in patients with chronic respiratory disease [52–55], where it reflects both the physiology of exercise limitation [56, 57] and the impact of exercise limitation on daily life [58]. Dyspnoea scores collected during the 6MWT exhibit good reliability, with the modified Borg dyspnoea scale [59] (ICCs 0.59–0.92) showing greater reliability than the 15-count dyspnoea scale (ICC 0.66) and visual analogue scale for dyspnoea (coefficient of variation 0.22) [1]; however, few studies have investigated these latter measures.

Subjective fatigue

Fatigue is a common feature in patients with chronic respiratory diseases, both as a local muscle phenomenon and general fatigue. This is reflected during the 6MWT, where COPD patients experienced more fatigue compared to healthy elderly subjects [60]. Patient-reported fatigue is commonly measured at the beginning and end of the 6MWT using the Borg scale [59], which exhibits moderate reliability [9, 61]. Fatigue measured during the 6MWT using the Borg scale is associated with lower 6MWT, slower gait speed, more severe airflow obstruction, more dyspnoea on exertion and lower HRQoL [1]. Notably, low-frequency muscle fatigue in the quadriceps is seldom found with the 6MWT, although low-frequency fatigue in distal leg muscles has been reported to be greater in COPD patients compared with controls [62].

6-min walk work

The 6-min walk work is the product of 6MWD and body weight, which may provide a better estimation of the work required to perform the test than distance alone. The 6MWD × weight product correlates more strongly with DLCO and V_{O₂peak} than 6MWD alone [63, 64]. To date, no studies have investigated the sensitivity of 6MWD × weight product to change over time. Additional studies are needed to better characterise the utility of the 6-min walk work in adults with respiratory disease.

In summary, the 6MWD is the primary outcome of the 6MWT and should be recorded on every test. The SpO₂ and HR should be measured continuously during the 6MWT, to ensure that the lowest SpO₂ and the end-test HR are recorded. Care should be taken that obtaining these measures does not affect performance. Current data indicate that the 6MWT has an excellent safety profile when the test is stopped if SpO₂ falls to <80%; few data are available to define the safety profile if desaturation to <80% is permitted. Dyspnoea and subjective fatigue should be measured before and after the 6MWT.

Identifying meaningful change in 6MWD

Minimal important difference for the 6MWD

Over the past 10 years, a number of new estimates of the MID for 6MWD have been published. Our systematic review [1] identified 11 studies, in COPD (six studies), ILD (three studies) and PAH (two studies). The majority of MID estimates from these studies are based on distribution-based methods (using statistical properties of the measure), rather than anchor-based methods (where change in 6MWD is related to another clinically important marker of change). Most values were generated for individuals with COPD participating in a rehabilitation programme rather than pharmacotherapy. The median estimate across all studies was 30 m [1]. There is currently little evidence to suggest that the MID varies according to patient characteristics, including the type of chronic lung disease or the baseline 6MWD. Most MID estimates were generated using group mean data and are best used to interpret group mean changes in 6MWD [65–67]. However, studies that derived the MID using methodologies that are applicable to individuals reported similar MID estimates [68, 69]. More studies are required to explore the magnitude of important changes in 6MWD with different interventions and to establish the MID in other chronic respiratory diseases.

In summary, the available evidence suggests a MID of 30 m for adult patients with chronic respiratory disease. There is some variability across studies and methods to determine the MID; however, based on the large evidence base now available, we can be confident that the MID lies between 25 and 33 m.

Responsiveness of the 6MWD

Few studies have been explicitly designed to assess the responsiveness of 6MWD to treatment effects, but a large number of randomised trials provide insights in this area. We chose the Cochrane reviews on exercise interventions for COPD [70, 71] and ILD [72] and the Cochrane review on endothelin receptor antagonists in PAH [73] to investigate the responsiveness of 6MWD to interventions of known efficacy. The meta-analyses for 6MWD showed highly statistically significant improvements in 6MWD, with effects between 34 and 78 m and effect sizes between 0.38 and 1.07 [1]. The standardised response means (mean change/standard deviation of change) ranged from 0.2 to 1.2 [1]. The 6MWD therefore appears to be responsive to treatment effects in patients with COPD, ILD and PAH. It should be noted that most of these values have been generated from rehabilitation-based studies.

Reference equations for 6MWD

The systematic review identified 16 published studies from 1998 to 2013 that included 6MWD prediction equations from healthy adults [1]. One additional study has been published since the systematic review [74]. These studies were conducted using a wide variety of populations and methodologies. Track lengths ranged from 20 to 50 m and the number of tests ranged from one to four. Application of these equations to an individual gives rise to substantial variation in the predicted distance.

Factors that may affect the 6MWD in healthy adults, and therefore the predicted distance, include methodology for 6MWT, percentage of peak HR achieved, height, age, sex, weight and perhaps race/ethnicity. The utility of % predicted values in assessing clinically meaningful change in 6MWD over time has not been investigated.

Due to the wide variation in predicted 6MWD generated by different equations, reference equations generated and verified in a local population should be applied where possible. A summary of reference equations can be found in the accompanying systematic review [1].

The ISWT and ESWT: measurement properties important to test conduct

Validity of the ISWT and ESWT

The ISWT is an externally paced maximal exercise test; the speed of walking is controlled by a series of pre-recorded signals. The speed of walking increases until the participant can no longer continue. The maximum duration of the test is 20 min.

Given the progressive nature of the ISWT, a strong relationship with performance on laboratory-based tests might be anticipated. Seven studies in COPD and one in lung cancer show that the $V'O_{2peak}$, estimated $V'O_{2peak}$, peak work and distance measured on ISWT show moderate to strong correlations with measures of maximal exercise performance on CPET [1], with no difference in measured oxygen uptake ($V'O_2$) between the tests [6, 75, 76]. HILL *et al.* [6] performed a minute-by-minute analysis, and both the ISWT and CPET demonstrated a linear response in $V'O_{2peak}$, suggesting that the two tests provoke a similar cardiopulmonary response. In summary, the current literature suggests that the ISWT is a valid measure of cardiopulmonary exercise capacity in COPD and provokes a similar physiological response to a CPET. More evidence in other disease populations is required.

The ESWT is a derivative of the ISWT, where patients walk for as long as possible at a predetermined percentage of maximum walking performance as assessed by the ISWT [77]. To set the speed for the ESWT, the ISWT must have been completed previously. The ESWT has been shown to elicit similar end-test HR and dyspnoea responses compared to a treadmill endurance test at the same intensity [77].

Reliability and learning effect for ISWT

Only a handful of studies have reported the reliability of the ISWT, with most data in COPD. One study documented an ICC of 0.88 (95% CI 0.83–0.92) [78]. Another study reported an ICC of 0.89 [79]. These two studies suggest that the association between test–retest walk distances is strong, with the majority of variability being attributable to between-subject differences. More studies are needed to confirm these findings.

There is a small but statistically significant difference between the first two ISWTs performed (mean differences of 20 and 25 m for tests performed on the same day, and 23.5 m for tests performed on different days) [6, 80, 81]. The effect of learning on the ISWT is large enough to be clinically important when evaluating change over time. It is recommended that two ISWTs be performed and the best distance recorded. It remains to be established whether one test would be sufficient where the ISWT is used as a one-off measure to stage disease or assess risk (e.g. likelihood of hospitalisation or mortality). Whether one test is sufficient if the test has previously been conducted, similar to the 6MWT, is still unclear. It is common to repeat the test once after an intervention, but whether this underestimates the impact of the intervention remains to be established. The reliability of the test in chronic respiratory diseases other than COPD has not been explored.

Reliability and learning effect for ESWT

Three studies have examined the reliability of the ESWT, all in COPD [6, 81, 82]. The differences between tests repeated on the same day were generally small and statistically nonsignificant (pooled mean difference +26 s). Two tests do not appear to be necessary, although it is acknowledged that the number of studies is limited. Measurements of HR, SpO₂ and modified Borg dyspnoea scale appear to repeat well during the test [1]. The reliability of the ESWT in other chronic respiratory diseases has not been examined.

Relationship of ISWT and ESWT to clinical outcomes

A small number of studies show that the ISWT is a significant predictor of survival and re-admission in people with COPD, with a lower distance predicting a greater risk of admission [83–85]. The relationship of ESWT to these outcomes is unknown.

Methodological factors affecting ISWT and ESWT performance

Unlike the 6MWT, the track for the ISWT and the ESWT is fixed, and alterations of the course have not been studied. The effect of encouragement has not been directly observed, but the external pacing of the tests may make it difficult to override the test protocol. The impact of supplemental oxygen is influenced by the mode of delivery. If patients are required to support a cylinder independently, oxygen supplementation confers little advantage in walking distance compared to air walking conditions [86], but if the oxygen (or heliox) is carried by a clinician/researcher, the benefit is magnified [87]. Accordingly, if supplemental oxygen is to be used during testing, the same approach should be taken for repeat testing, with the device and the flow rate remaining constant.

Monitoring and reporting for ISWT and ESWT

Safety

Adverse events have not been directly studied or reported in association with either the ISWT or the ESWT. We were unable to find any literature describing complications of conducting the shuttle tests. To date, there is no clear guidance on the value of monitoring SpO₂ and the level to which this may fall in any individual has yet to be described. However, consensus suggests that the ISWT and the ESWT should be discontinued if SpO₂ falls below 80%. The test has been reported in patients with cardiac disease [88–90] with no adverse events; to date the test has not been used for patients with PAH.

Measurements

The primary outcome of the ISWT is distance, reported as an accumulation of 10-m lengths. The minimum distance is 0 m if patients fail to complete the first 10 m, and the maximum is 1020 m. The ESWT, like all endurance tests, is reported as time (minutes and seconds); although it can be expressed as distance completed, this is less commonly reported for endurance tests in the literature. The speed that the participant walks is chosen from 16 available speeds (1.78–6.00 km·h⁻¹), with the speed calculated from the

performance on the ISWT. Additional outcomes have been reported; these include SpO₂, HR responses, dyspnoea, fatigue and the reason for terminating the test.

Identifying meaningful change in ISWT and ESWT

Minimal important difference for the ISWT

The MID for the ISWT has been described in one paper that was specifically designed to assess this threshold [91] and confirmed within a second paper [92]. Both studies used a similar approach, with a preference-based anchor method using rehabilitation as the intervention. The original paper described that a change of 47.5 m (approximately five shuttles) was associated with feeling “slightly better”, while a change of 78.7 m (approximately eight shuttles) was associated with the next rating (“better”). The authors concluded that the MID for the ISWT was 47.5 m. More studies are required, exploring different interventions and different approaches, to describe the MID in COPD. The MID for other chronic respiratory diseases has not been explored.

Minimal important difference for the ESWT

The MID for the ESWT in patients receiving pulmonary rehabilitation or bronchodilation has been estimated using a distribution-based approach and anchor-based method (change in ESWT time and distance was related to patients’ perception of change from baseline) [93]. Bronchodilation data indicated that a change of 65 s (95% CI 45–85 s) or 85 m (95% CI 60–115 m), representing 13–15% of baseline, was associated with a one-point change on the Likert rating scale and thus likely to be perceivable to patients. An estimate of the MID could not be obtained from the pulmonary rehabilitation data, although preliminary data suggest this is in the region of 180 s [93]. It is possible that the MID may be context or intervention specific, although to date this has not been shown for 6MWD.

Responsiveness of the shuttle walk tests

Despite the ISWT being employed in a number of studies, only eight studies were explicitly designed to evaluate the responsiveness to treatment of the ISWT and/or ESWT [86, 94–100]. These studies suggest that the ISWT and ESWT are both responsive. The standardised response means (mean change/standard deviation of change) range from 0.72 to 1.55 for the ISWT and from 0.52 to 1.27 for the ESWT [1].

Reference equations for ISWT and ESWT

Three papers have described reference values for the ISWT, two from South America [101, 102] and one from the UK [103]. There is a need for more data, including diversity in the country of origin. Existing data suggest that age, sex and body mass index are important variables. Data from a single centre in the UK [1] included measures of strength (quadriceps maximum voluntary contraction) and physical activity (Duke Physical Activity Status Index and a physical activity monitor), in an attempt to further explain the variability; however, these additions did not improve the reference equation.

To date there has been no attempt to identify reference equations for the ESWT.

Selecting a field walking test

It is beyond the scope of this Technical Standard to recommend one field test over another. The systematic review underpinning this document did not address the question of the relative merits of each test. However, some general considerations that may influence test selection are outlined here.

Field walking tests may be performed to identify the individual’s exercise capacity (peak exercise capacity, functional exercise capacity or endurance), factors limiting exercise performance (dyspnoea, subjective fatigue, musculoskeletal limitations) and often their response to an intervention. The field tests can also be used to identify a threshold to predict survival and the likelihood of a hospital readmission, with a more extensive body of evidence reporting use of 6MWD rather than ISWT or ESWT for this purpose [1]. Prescription of exercise intensity for pulmonary rehabilitation, using the established principles of exercise training, may also be a consideration. The uses of the 6MWT and the ISWT/ESWT have been reported in all of these circumstances [1]. Practical considerations include whether sufficient space is available. If the test of choice is the 6MWT then the test should be conducted as recommended along a course at least 30 m in length; if this space is not available then consideration should be given to using the ISWT/ESWT. Both the 6MWT and ISWT require two tests to be performed prior to an intervention [1] and thus the time taken to conduct each test is comparable.

The 6MWT and ISWT/ESWT offer quite different protocols: the 6MWT is self-paced, and the shuttle tests are externally paced. Although both tests generally provoke a $\dot{V}O_2$ similar to that seen on a CPET [6, 75, 104–106], the precise pattern of response may be different for the externally paced tests (ISWT/ESWT) compared to a self-paced test (6MWT). The response of the ISWT mirrors the physiological response

TABLE 3 Equipment required for conduct of field walking tests

At least one chair, positioned at one end of the walking course
A validated scale to measure dyspnoea and subjective fatigue
Sphygmomanometer for blood pressure measurement
Pulse oximeter
Stopwatch
Pre-measured marks along the track/corridor
Access to oxygen and telephone in case of an emergency
An emergency plan
Portable supplemental oxygen if required by patient to perform exercise test
Clipboard with reporting sheet and pen

observed in an incremental laboratory-based test, with an incremental increase in $V'O_2$ over time, whereas the self-paced 6MWT shows a steady-state $V'O_2$ profile after the third minute [3, 75, 104]. Because of the similarity in response of the ISWT and CPET, prescribing an exercise regimen as a percentage of peak performance on a field walking test may be easier with the ISWT than the 6MWT, because of the incremental nature of the test. Responses to the ESWT show a significantly more rapid rise in $V'O_2$ and ventilation than during the 6MWT, but similar end-test values [95]. The $V'O_{2peak}$ on ESWT does not differ significantly when compared to the ISWT and 6MWT [6]. The physiological responses to each test are reported in more detail in the systematic review [1].

The comparative sensitivity of field walking tests has been examined in small studies that have looked at rehabilitation or bronchodilation as the intervention, predominantly in COPD. PEPIN *et al.* [95] observed an enhanced response in the ESWT compared to the 6MWT after an acute administration of a bronchodilator, with standardised response means of 0.66 and 0.42, respectively. Similarly, EATON *et al.* [98] reported that, after a course of pulmonary rehabilitation, the magnitude of the change was proportionally greater on the ESWT than the 6MWT (92% versus 17%). The ESWT has also proven to be more responsive than the 6MWT in a randomised trial of an exercise intervention for COPD [107]. These results suggest that the ESWT may be more sensitive to change than the 6MWT, following bronchodilation or pulmonary rehabilitation.

Given the differing protocols, physiological patterns of response, measurement properties and circumstances in which field walking tests are applied, the choice of test should be carefully considered. Regardless of the test selected, robust results can only be obtained with careful attention to testing procedures as described in the following sections.

Test procedures applicable to all field walking tests

Equipment

The equipment required to conduct a field walking test is listed in table 3.

Test location and staffing

The test should be conducted along a quiet course, physiotherapy gym or dedicated exercise testing room. A comfortable temperature is important and air conditioning should be available if needed. Testing should be performed in a location where a rapid, appropriate response to an emergency is possible. The appropriate location of a crash cart should be determined by the physician supervising the facility. Supplies that must be available include oxygen, sublingual nitroglycerine and salbutamol (metered dose inhaler or nebuliser). A telephone or other means of calling for help should be available in case of emergency.

The assessor performing the test should be certified in cardiopulmonary resuscitation with a minimum of Basic Life Support certification. Training, experience and certification in related healthcare fields are also desirable. A certified individual should be readily available to respond if needed. Physicians are not required to be present during all tests. The physician ordering the test or a supervising laboratory physician may decide whether physician attendance at a specific test is required.

Patient assessment

Given that all three field-based exercise tests can elicit a $V'O_{2peak}$ and peak HR that are similar to the CPET [1], absolute and relative contraindications for exercise testing should be consistent with recommendations for maximal exercise testing (table 4) [108]. Patients with any of these findings should be referred to the physician ordering or supervising the test for individual clinical assessment and a decision about the conduct of the test. Stable exertional angina is not an absolute contraindication for field walking tests, but patients with these symptoms should perform the test after using their anti-angina medication, and rescue

TABLE 4 Absolute and relative contraindications for field walking tests

Absolute	Relative
Acute myocardial infarction (3–5 days)	Left main coronary stenosis or its equivalent
Unstable angina	Moderate stenotic valvular heart disease
Uncontrolled arrhythmias causing symptoms or haemodynamic compromise	Severe untreated arterial hypertension at rest (200 mmHg systolic, 120 mmHg diastolic)
Syncope	Tachyarrhythmias or bradyarrhythmias
Active endocarditis	High-degree atrioventricular block
Acute myocarditis or pericarditis	Hypertrophic cardiomyopathy
Symptomatic severe aortic stenosis	Significant pulmonary hypertension
Uncontrolled heart failure	Advanced or complicated pregnancy
Acute pulmonary embolus or pulmonary infarction	Electrolyte abnormalities
Thrombosis of lower extremities	Orthopaedic impairment that prevents walking
Suspected dissecting aneurysm	
Uncontrolled asthma	
Pulmonary oedema	
Room air SpO ₂ at rest ≤85% [#]	
Acute respiratory failure	
Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis)	
Mental impairment leading to inability to cooperate	

SpO₂: arterial oxygen saturation measured by pulse oximetry. [#]: exercise patient with supplemental oxygen. Reproduced from [108] with permission from the publisher.

nitrate medication should be readily available. All comorbidities and medication use should be recorded prior to the test.

Patient preparation

Patients should wear comfortable clothing and appropriate shoes for walking. Patients should use their usual walking aids during the test and this should be documented on the assessment form. Patients should not have exercised vigorously within 2 h of beginning the test but should have taken their usual medications. All subsequent testing occasions should occur at about the same time of day to minimise intra-day variability, including variability in self-paced tests (6MWT) associated with bronchodilator use [109]. A warm-up is not permitted prior to commencing the test, neither is a shortened version of the test. If respiratory function tests are to be performed on the same day, this should occur prior to exercise testing, to avoid the confounding effects of exercise on these measures. The patients should then rest for at least 15 min before commencing an exercise test.

Use of oxygen

If a patient is on long-term oxygen therapy, oxygen should be given at their standard flow rate or as directed by a physician or a protocol. For any test where the outcome is distance, oxygen flow should be held constant throughout the test. If the purpose of the exercise test is to compare distance walked between tests, any subsequent test should be performed using the same oxygen conditions, in order to make a valid comparison between testing occasions. If oxygen supplementation is needed during the walks and serial tests are planned, then oxygen should be delivered in the same manner (flow rate and delivery device) for all subsequent walks. If the flow rate must be increased for subsequent visits due to worsening gas exchange, this should be noted on the worksheet and considered during interpretation of any changes in performance.

The type of oxygen delivery device should also be noted on the report: for instance, whether the subject carried liquid oxygen or pushed or pulled an oxygen tank, and whether the delivery was pulsed or continuous. Assessors should avoid transportation of the oxygen source where possible; however, if the subject is not able to control/carry/manage their own oxygen cylinder, the assessor should try to walk slightly behind the subject to avoid setting the walking pace. It should be clearly documented how the assessor has assisted with the transport of the oxygen, so any subsequent walk tests with the same subject can be performed in the same manner. Oxygen is not to be titrated during any of the tests where distance is a measured outcome. If oxygen titration is desired, this should be done during a separate test.

TABLE 5 Standardised instructions for the 6-min walk test

The aim of this test is to walk as far as possible for 6 minutes. You will walk along this hallway between the markers, as many times as you can in 6 minutes.
I will let you know as each minute goes past, and then at 6 minutes I will ask you to stop where you are. 6 minutes is a long time to walk, so you will be exerting yourself. You are permitted to slow down, to stop, and to rest as necessary, but please resume walking as soon as you are able.
Remember that the objective is to walk AS FAR AS POSSIBLE for 6 minutes, but don't run or jog.
Do you have any questions?

Medications

Patients should be instructed to take all usual medications. The type of medication, dose and number of hours it was taken before the test should be noted. Significant improvement in the distance walked or the dyspnoea scale after administration of bronchodilators has been demonstrated in patients with COPD [93–96], although this may be small and clinically insignificant for the 6MWT [95, 110].

Measurements

Patients should rest in a chair, located near the starting position, before the test starts. Absolute and relative contraindications should be checked for prior to test commencement (table 4). The following measurements should be obtained at rest: SpO₂ and HR from pulse oximetry, baseline dyspnoea and fatigue using a reproducible scale, and systemic blood pressure, if not recently documented [108].

Immediately prior to the test

The assessor should provide standardised instructions, either verbally for the 6MWT (table 5) or from the ISWT or ESWT audio recording. The patient should be positioned at the starting line. For the 6MWT, the timer should be started as soon as the patient starts to walk. The recorded instructions of the ISWT and ESWT will prompt the individual to start.

A pulse oximeter should be used for continuous measurement of SpO₂ and HR. The assessor should not “pace” the patient during the test, but should walk behind such that measures of nadir SpO₂ and end-test HR can be recorded without influencing the patient's movement. The assessor should ensure that the probe is placed such that a quality signal is obtained.

Immediately on test cessation

The SpO₂ and pulse rate should be recorded from the oximeter, and the patient should be asked to rate their dyspnoea and subjective fatigue on the standardised scale. In addition, it is important to understand the reason for test termination/limitation, so patients should be asked why they could not walk any further. It is common for patients to report either dyspnoea or leg fatigue as the primary reason for a restricted performance.

Reasons for the assessor to stop an exercise test

In some individuals, profound desaturation (SpO₂ <80%) may occur during a walking-based exercise test. Use of a 6MWT protocol that directs test cessation when SpO₂ falls to <80% is associated with an extremely low rate of adverse events [35]; this has not been reported for the ISWT or ESWT. Few data are available to determine the risk if the test is not stopped when SpO₂ falls below 80%. Ceasing a test when SpO₂ falls to <80% is also consistent with the recommendations for incremental exercise testing [108]. If SpO₂ recovers to ≥85% during the 6MWT, the patient may be asked to recommence walking.

Other reasons for test cessation include chest pain, intolerable dyspnoea, leg cramps, staggering, diaphoresis, and a pale or ashen appearance. If a test is stopped for any of these reasons, the patient should sit or lie supine as appropriate. The following should be obtained based on the judgment of the assessor: blood pressure, pulse rate, SpO₂ and a physician evaluation. Oxygen should be administered as appropriate.

Test repetition

To establish a stable baseline for the 6MWT and ISWT so that change over time can be detected, two tests must be completed. These can be performed on the same day but there must be an interval between tests of at least 30 min and measures of HR and SpO₂ must have returned to baseline prior to the second test.

Quality assurance

Consistency of testing procedures and conditions is critical to ensure that results are of good quality. It is important that all assessors are familiar with the test procedures, as the test requires clear processes to be followed.

TABLE 6 Standardised encouragement for the 6-min walk test

1 min	You are doing well. You have 5 minutes to go.
2 min	Keep up the good work. You have 4 minutes to go.
3 min	You are doing well. You are halfway.
4 min	Keep up the good work. You have only 2 minutes left.
5 min	You are doing well. You have only 1 minute to go.
6 min	Please stop where you are.
If the patient stops during the test, every 30 s once SpO₂ is ≥85%	Please resume walking whenever you feel able.

SpO₂: arterial oxygen saturation measured by pulse oximetry.

For the ISWT and ESWT, the assessor must be able to walk at exactly the first speed of walking to pace the patient; this is particularly important for patients with a higher functional capacity where their natural speed of walking is much faster than the very slow pace required on the first level of the ISWT. All assessors should have their performance peer reviewed to ensure that performance of the tests is in accordance with the Technical Standard. Ideally, quality assurance testing should require the assessor to conduct the test on participants with a range of functional exercise capacity.

It must be ensured that the pulse oximeter is operating according to the manufacturer's instructions and that the track is accurately measured. The effects of any changes in testing scenario (*e.g.* location, equipment) should be evaluated to assess their effect on test outcomes. Any changes in procedures should be reviewed and approved by the programme director. Consistent documentation must be ensured for every test and a regular audit should be considered, to ensure that important procedures have been followed (*e.g.* recording of appropriate physiological signals at baseline and end-test, documentation of nadir SpO₂, end-test HR and 6MWD, consistent use of oxygen, appropriate test repetition).

Testing protocol for 6MWT

Course

The 6MWT should be performed along a flat, straight course with a hard surface with little pedestrian traffic. It is recommended that the walking course be 30 m or more in length, to be consistent with the courses on which reference equations have been generated [1]. The ends of the course should be marked such that they are easily visible to patients.

Conduct

The patient should be encouraged every 60 s using the standard phrases (table 6). Other words of encouragement and other nonverbal prompts should not be used. If the patient stops walking during the test, the timer must not be stopped. The patient should be allowed to rest while sitting or standing, as they prefer. While the patient is stopped, standardised encouragement should be provided every 30 s (table 6). The time that the patient stopped and the time that walking is recommenced should be recorded.

Recording performance of the 6MWT

The primary outcome to be reported is 6MWD. The number of laps and any additional distance covered (the number of metres or feet in the final partial lap) should be recorded. The total distance walked is calculated, rounding to the nearest metre or foot. If the patient stopped during the test, the total time stopped, the number of stops and the average walking speed over the 6 min are also reported [111]. In patients who cannot walk for 6 min, this may provide alternative metrics for detecting change over time [111] and may facilitate exercise prescription [112]. It is optional to report the 6MWD as a percentage of predicted. If the % predicted 6MWD is reported, the reference equations used should be stated. Lowest SpO₂, end-test HR and symptom scores obtained before and after the test should also be reported. A sample recording form can be found in the online supplementary material (table S1).

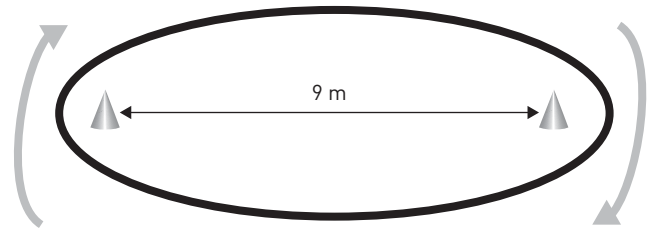
Testing protocol for ISWT

Course

The course is 10 m in length and is identified for the patient by two cones with an inset of 0.5 m from either end (fig. 1), thus avoiding abrupt changes in direction [113].

At the beginning of the test the instructions are played to the patient from an audio recording (table 7). Once the instructions have been played, and it is confirmed that the patient has understood the task, the

FIGURE 1 Course layout for the incremental and endurance shuttle walk tests. Cones are inset 0.5 m from either end to avoid abrupt changes in direction.



patient is positioned at one end of the course in preparation to start the test. The speed at which the patient should walk is directed by an audio signal and cannot be overridden. There is a triple bleep indicating the test has started: at this point the participant commences walking and the timer is activated.

Conduct of the test

It is important for the assessor to watch the patient but also to ensure they keep count of the number of lengths as the subject completes them, throughout the duration of the test. It is advisable to time the performance as an additional measure, to confirm manual recording of the number of shuttles completed. As the speed of walking increases every minute, indicated by a triple bleep [113], the patient should be advised: “You now need to increase your speed of walking.” During the test, only one verbal cue can be used to encourage the patient to pick up their speed: “You need to increase your speed to keep up with the test.”

Termination of the test

The test is terminated when either 1) the patient indicates that they are unable to continue, 2) the operator determines that the patient is not fit to continue, or 3) the operator assesses that the patient was unable to sustain the speed and cover the distance to the cone prior to the beep sounding [113].

Operator termination of the test

The operator will be required to terminate the test if the patient fails to reach the cone/marker in the time allowed [113]. This is defined as the patient being >0.5 m away from the cone when the bleep sounds on a second successive 10-m length. When the patient is just outside the 0.5-m marker they are advised to increase their speed of walking; if the patient fails to do so then the test is terminated and the distance recorded.

The test should be discontinued by the operator if SpO_2 falls below 80% as described in the ATS/American College of Chest Physicians (ACCP) statement on cardiopulmonary exercise testing [108].

TABLE 7 Incremental and endurance shuttle walk test instructions

Incremental shuttle walk test instructions

The object of the progressive shuttle walking test is to walk as long as possible, there and back along the 10-metre course, keeping to the speed indicated by the bleeps on the audio recording. You will hear these bleeps at regular intervals.

You should walk at a steady pace, aiming to turn around the cone at one end of the course when you hear the first bleep, and at the other end when you hear the next. At first, your walking speed will be very slow, but you will need to speed up at the end of each minute. Your aim should be to follow the set rhythm for as long as you can. Each single bleep signals the end of a shuttle and each triple bleep signals an increase in walking speed. You should stop walking only when you become too breathless to maintain the required speed or can no longer keep up with the set pace.

The test is maximal and progressive. In other words, it is easier at the start and harder at the end. The walking speed for the first minute is very slow. You have 20 seconds to complete each 10-metre shuttle, so don't go too fast. The test will start in 15 seconds, so get ready at the start now. Level one starts with a triple bleep after the 4-second countdown.

Endurance shuttle walk test instructions

Walking test level [1 to 16]. The instructions below are repeated for all 16 levels.

The walking speed for the first 2 minutes is fairly slow, so don't go too fast. The test will start in 10 seconds so get ready at the start now. The test starts with a triple bleep after a 4-second countdown. At the next triple bleep increase your walking speed.

Participant termination of the test

The patient may terminate the test if they are unable to continue. In respiratory disease, the most common reason for terminating the test is excessive dyspnoea; however, other reasons may include fatigue (commonly leg fatigue) or pain (knee/hip/low back pain).

Recording performance of the test

The assessor should calculate the distance walked, in metres, including the last 10-m length that was completed, and record this on the form available (see online supplementary material table S2).

Testing protocol for ESWT

Course

The test is conducted along the same course as described for the ISWT (fig. 1) [113].

Conduct of the test

Unlike the ISWT, the ESWT is not incremental and is performed at a constant speed, but there is a warm-up period of ~1.5 min [77]. At this point, there are standardised instructions for the participant played from the audio recording, advising the individual that at the next bleep the speed of walking will increase (table 7). This is the speed at which the test is performed. It is important to pre-define the speed at which the test is going to be conducted. This can be calculated from the ISWT: the speed may be taken from a pre-defined percentage of peak performance on the ISWT (e.g. 70–85% estimated $V'O_{2peak}$) [114] or a percentage of the peak speed achieved [115]. Once the instructions have been played to the patient, they should be directed to one end of the course. A triple bleep indicates that the test has started [77]. The initial stages of the test are at a slower speed and are a warm-up for the participant. After the warm-up period, the speed of walking increases; this is advised on the audio recording at the end of the warm-up period. The timer is started at the end of the warm-up period. Participants are then paced for the first two shuttles. During the test, only one verbal cue can be used to encourage the patient to pick up their speed: “You need to increase your speed to keep up with the test.”

Termination of the ESWT

The procedure to terminate the test is as described for the ISWT [113].

Recording performance of the test

It is conventional for endurance performance to be recorded as time (in seconds). It is important that the speed of walking and time are recorded. A sample scoring sheet is included in the online supplementary material (table S2).

Key changes in this updated Technical Standard

Absolute and relative contraindications for field walking tests

Research published since 2002 has shown that, in adults with moderate chronic respiratory disease, the 6MWT and ISWT elicit a $V'O_{2peak}$ that is comparable to that on CPET [3–6, 8]. As a result, the absolute and relative contraindications for CPET have been adopted for field walking tests of exercise capacity.

Continuous measurement of S_{pO_2}

New data show both the importance of nadir S_{pO_2} during the 6MWT as a marker of prognosis [38, 46, 116–119] and that end-test S_{pO_2} frequently does not reflect this important value [40, 41]. These factors, together with improvements in pulse oximetry technology in managing motion artefact, have made it feasible and desirable to measure S_{pO_2} continuously during field walking tests.

6MWT repetition

There are now consistent and compelling data showing a learning effect for the 6MWT [1, 9]. As a result, it is recommended that two 6MWTs are performed when the test is used to measure change over time.

Addition of the ISWT and ESWT

The ISWT and ESWT have emerged as robust and useful tests of exercise capacity in chronic respiratory disease [1]. The standard operating procedures for these tests are described here for the first time.

Common testing procedures for field walking tests

Testing procedures, such as test staffing, patient assessment, patient preparation, use of oxygen and medications, and quality assurance, are now consistent across the three field walking tests described in this Technical Standard.

Acknowledgements

The authors' affiliations are as follows. Anne E. Holland: Dept of Physiotherapy, La Trobe University, Melbourne, Australia, Dept of Physiotherapy, Alfred Health, Melbourne, Australia, and Institute for Breathing and Sleep, Austin Health, Melbourne, Australia; Martijn A. Spruit: Dept of Research and Education, CIRO+ Centre of Expertise for Chronic Organ Failure, Horn, The Netherlands, and REVAL – Rehabilitation Research Center, BIOMED – Biomedical Research Institute, Faculty of Medicine and Life Sciences, Hasselt University, Diepenbeek, Belgium; Thierry Troosters and Carlos Augusto Camillo: Faculty of Kinesiology and Rehabilitation Sciences, Dept of Rehabilitation Sciences, Katholieke Universiteit Leuven, Leuven, Belgium; Milo A. Puhan: Institute for Social and Preventive Medicine, University of Zurich, Zurich, Switzerland; Véronique Pepin: Axe maladies chroniques, Centre de recherche de l'Hôpital du Sacré-Coeur de Montréal, Montreal, QC, Canada, and Dept of Exercise Science, Faculty of Arts and Science, Concordia University, Montreal, QC, Canada; Didier Saey: Centre de recherche, Institut Universitaire de cardiologie et de pneumologie de Québec, Québec, QC, Canada, and Faculté de médecine, Université Laval, Québec, QC, Canada; Meredith C. McCormack: Johns Hopkins University, Pulmonary and Critical Care Medicine, Baltimore, MD, USA; Brian W. Carlin: Drexel University School of Medicine, Pittsburgh, PA, USA, and Sleep Medicine and Lung Health Consultants, Pittsburgh, PA, USA; Frank C. Sciurba: University of Pittsburgh School of Medicine, Pittsburgh, PA, USA; Fabio Pitta and Nidia A. Hernandez: Laboratory of Research in Respiratory Physiotherapy, Dept of Physiotherapy, Universidade Estadual de Londrina, Londrina, Brazil; Jack Wanger: ATS Proficiency Standards for Pulmonary Function Laboratories Committee, Rochester, MN, USA; Neil MacIntyre: Duke University, Durham, NC, USA; David A. Kaminsky: University of Vermont College of Medicine, Burlington, VT, USA; Bruce H. Culver: Pulmonary and Critical Care Medicine, University of Washington, Seattle, WA, USA; Susan M. Revill: Clinical Diagnostix Ltd, Derby, UK; Vasileios Andrianopoulos: Dept of Research and Education, CIRO+ Centre of Expertise for Chronic Organ Failure, Horn, The Netherlands; Katy E. Mitchell: Centre for Exercise and Rehabilitation Science, University Hospitals of Leicester NHS Trust, Leicester, UK; Annemarie L. Lee: Dept of Physiotherapy, Alfred Health, Melbourne, Australia, and Institute for Breathing and Sleep, Austin Health, Melbourne, Australia; Catherine J. Hill: Institute for Breathing and Sleep, Austin Health, Melbourne, Australia, and Dept of Physiotherapy, Austin Health, Melbourne, Australia; Sally J. Singh: Centre for Exercise and Rehabilitation Science, University Hospitals of Leicester NHS Trust, Leicester, UK.

References

- 1 Singh SJ, Puhan MA, Andrianopoulos V, *et al*. An official systematic review of the European Respiratory Society/ American Thoracic Society: measurement properties of field walking tests in chronic respiratory disease. *Eur Respir J* 2014; 44: 1447–1478.
- 2 ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002; 166: 111–117.
- 3 Troosters T, Vilaro J, Rabinovich R, *et al*. Physiological responses to the 6-min walk test in patients with chronic obstructive pulmonary disease. *Eur Respir J* 2002; 20: 564–569.
- 4 Satake M, Shioya T, Takahashi H, *et al*. Ventilatory responses to six-minute walk test, incremental shuttle walking test, and cycle ergometer test in patients with chronic obstructive pulmonary disease. *Biomed Res* 2003; 24: 309–316.
- 5 Luxton N, Alison JA, Wu J, *et al*. Relationship between field walking tests and incremental cycle ergometry in COPD. *Respirology* 2008; 13: 856–862.
- 6 Hill K, Dolmage TE, Woon L, *et al*. Comparing peak and submaximal cardiorespiratory responses during field walking tests with incremental cycle ergometry in COPD. *Respirology* 2012; 17: 278–284.
- 7 Deboeck G, Niset G, Vachery JL, *et al*. Physiological response to the six-minute walk test in pulmonary arterial hypertension. *Eur Respir J* 2005; 26: 667–672.
- 8 Blanco I, Villaquirán C, Valera JL, *et al*. Consumo máximo de oxígeno durante la prueba de marcha de 6 minutos en la enfermedad pulmonar intersticial difusa y en la hipertensión pulmonar [Peak oxygen uptake during the six-minute walk test in diffuse interstitial lung disease and pulmonary hypertension]. *Arch Bronconeumol* 2010; 46: 122–128.
- 9 Hernandez NA, Wouters EF, Meijer K, *et al*. Reproducibility of 6-minute walking test in patients with COPD. *Eur Respir J* 2011; 38: 261–267.
- 10 Spencer LM, Alison JA, McKeough ZJ. Six-minute walk test as an outcome measure: are two six-minute walk tests necessary immediately after pulmonary rehabilitation and at three-month follow-up? *Am J Phys Med Rehabil* 2008; 87: 224–228.
- 11 Chandra D, Kulkarni HS, Sciurba F. Learning from the learning effect in the six-minute-walk test. *Am J Respir Crit Care Med* 2012; 185: 684.
- 12 Cote CG, Pinto-Plata VM, Marin JM, *et al*. The modified BODE index: validation with mortality in COPD. *Eur Respir J* 2008; 32: 1269–1274.
- 13 Spruit MA, Polkey MI, Celli B, *et al*. Predicting outcomes from 6-minute walk distance in chronic obstructive pulmonary disease. *J Am Med Dir Assoc* 2012; 13: 291–297.
- 14 Stevens D, Elpern E, Sharma K, *et al*. Comparison of hallway and treadmill six-minute walk tests. *Am J Respir Crit Care Med* 1999; 160: 1540–1543.
- 15 de Almeida FG, Victor EG, Rizzo JA. Hallway versus treadmill 6-minute-walk tests in patients with chronic obstructive pulmonary disease. *Respir Care* 2009; 54: 1712–1716.
- 16 Brooks D, Solway S, Weinacht K, *et al*. Comparison between an indoor and an outdoor 6-minute walk test among individuals with chronic obstructive pulmonary disease. *Arch Phys Med Rehabil* 2003; 84: 873–876.
- 17 Bansal V, Hill K, Dolmage TE, *et al*. Modifying track layout from straight to circular has a modest effect on the 6-min walk distance. *Chest* 2008; 133: 1155–1160.
- 18 Sciurba F, Criner GJ, Lee SM, *et al*. Six-minute walk distance in chronic obstructive pulmonary disease: reproducibility and effect of walking course layout and length. *Am J Respir Crit Care Med* 2003; 167: 1522–1527.
- 19 Beekman E, Mesters I, Hendriks EJ, *et al*. Course length of 30 metres versus 10 metres has a significant influence on six-minute walk distance in patients with COPD: an experimental crossover study. *J Physiother* 2013; 59: 169–176.
- 20 Gupta R, Goldstein R, Brooks D. The acute effects of a rollator in individuals with COPD. *J Cardiopulm Rehabil* 2006; 26: 107–111.

- 21 Honeyman P, Barr P, Stubbing DG. Effect of a walking aid on disability, oxygenation, and breathlessness in patients with chronic airflow limitation. *J Cardiopulm Rehabil* 1996; 16: 63–67.
- 22 Probst VS, Troosters T, Coosemans I, *et al.* Mechanisms of improvement in exercise capacity using a rollator in patients with COPD. *Chest* 2004; 126: 1102–1107.
- 23 Roomi J, Yohannes AM, Connolly MJ. The effect of walking aids on exercise capacity and oxygenation in elderly patients with chronic obstructive pulmonary disease. *Age Ageing* 1998; 27: 703–706.
- 24 Solway S, Brooks D, Lau L, *et al.* The short-term effect of a rollator on functional exercise capacity among individuals with severe COPD. *Chest* 2002; 122: 56–65.
- 25 Vaes AW, Annegarn J, Meijer K, *et al.* The effects of a “new” walking aid on exercise performance in patients with COPD: a randomized crossover trial. *Chest* 2012; 141: 1224–1232.
- 26 Davidson AC, Leach R, George RJ, *et al.* Supplemental oxygen and exercise ability in chronic obstructive airways disease. *Thorax* 1988; 43: 965–971.
- 27 Fujimoto K, Matsuzawa Y, Yamaguchi S, *et al.* Benefits of oxygen on exercise performance and pulmonary hemodynamics in patients with COPD with mild hypoxemia. *Chest* 2002; 122: 457–463.
- 28 Rooyackers JM, Dekhuijzen PN, Van Herwaarden CL, *et al.* Training with supplemental oxygen in patients with COPD and hypoxaemia at peak exercise. *Eur Respir J* 1997; 10: 1278–1284.
- 29 Jolly EC, Di Boscio V, Aguirre L, *et al.* Effects of supplemental oxygen during activity in patients with advanced COPD without severe resting hypoxemia. *Chest* 2001; 120: 437–443.
- 30 McDonald CF, Blyth CM, Lazarus MD, *et al.* Exertional oxygen of limited benefit in patients with chronic obstructive pulmonary disease and mild hypoxemia. *Am J Respir Crit Care Med* 1995; 152: 1616–1619.
- 31 Crisafulli E, Beneventi C, Bortolotti V, *et al.* Energy expenditure at rest and during walking in patients with chronic respiratory failure: a prospective two-phase case-control study. *PLoS One* 2011; 6: e23770.
- 32 Woodcock AA, Gross ER, Geddes DM. Oxygen relieves breathlessness in “pink puffers”. *Lancet* 1981; 1: 907–909.
- 33 Guyatt GH, Pugsley SO, Sullivan MJ, *et al.* Effect of encouragement on walking test performance. *Thorax* 1984; 39: 818–822.
- 34 Weir NA, Brown AW, Shlobin OA, *et al.* The influence of alternative instruction on 6-min walk test distance. *Chest* 2013; 144: 1900–1905.
- 35 Jenkins S, Čecins N. Six-minute walk test: observed adverse events and oxygen desaturation in a large cohort of patients with chronic lung disease. *Intern Med J* 2011; 41: 416–422.
- 36 Park JH, Jegal Y, Shim TS, *et al.* Hypoxemia and arrhythmia during daily activities and six-minute walk test in fibrotic interstitial lung diseases. *J Korean Med Sci* 2011; 26: 372–378.
- 37 van Gestel AJ, Clarenbach CF, Stöwhas AC, *et al.* Prevalence and prediction of exercise-induced oxygen desaturation in patients with chronic obstructive pulmonary disease. *Respiration* 2012; 84: 353–359.
- 38 Casanova C, Cote C, Marin JM, *et al.* Distance and oxygen desaturation during the 6-min walk test as predictors of long-term mortality in patients with COPD. *Chest* 2008; 134: 746–752.
- 39 Poulain M, Durand F, Palomba B, *et al.* 6-minute walk testing is more sensitive than maximal incremental cycle testing for detecting oxygen desaturation in patients with COPD. *Chest* 2003; 123: 1401–1407.
- 40 Chuang ML, Lin IF, Chen SP. Kinetics of changes in oxyhemoglobin saturation during walking and cycling tests in COPD. *Respir Care* 2014; 59: 353–362.
- 41 Fiore C, Lee A, McDonald C, *et al.* Should oxyhaemoglobin saturation be monitored continuously during the 6-minute walk test? *Chron Respir Dis* 2011; 8: 181–184.
- 42 Lettieri CJ, Nathan SD, Browning RF, *et al.* The distance-saturation product predicts mortality in idiopathic pulmonary fibrosis. *Respir Med* 2006; 100: 1734–1741.
- 43 Modrykamien AM, Gudavalli R, McCarthy K, *et al.* Echocardiography, 6-minute walk distance, and distance-saturation product as predictors of pulmonary arterial hypertension in idiopathic pulmonary fibrosis. *Respir Care* 2010; 55: 584–588.
- 44 Alhamad EH, Shaik SA, Idrees MM, *et al.* Outcome measures of the 6 minute walk test: relationships with physiologic and computed tomography findings in patients with sarcoidosis. *BMC Pulm Med* 2010; 10: 42.
- 45 Bourbonnais JM, Malaisamy S, Dalal BD, *et al.* Distance saturation product predicts health-related quality of life among sarcoidosis patients. *Health Qual Life Outcomes* 2012; 10: 67.
- 46 Flaherty KR, Andrei AC, Murray S, *et al.* Idiopathic pulmonary fibrosis: prognostic value of changes in physiology and six-minute-walk test. *Am J Respir Crit Care Med* 2006; 174: 803–809.
- 47 Pimenta SP, Rocha RB, Baldi BG, *et al.* Desaturation–distance ratio: a new concept for a functional assessment of interstitial lung diseases. *Clinics* 2010; 65: 841–846.
- 48 Mandrusiak A, Maurer C, MacDonald J, *et al.* Functional capacity tests in young people with cystic fibrosis. *N Z J Physiother* 2009; 37: 13–16.
- 49 Swigris JJ, Swick J, Wamboldt FS, *et al.* Heart rate recovery after 6-min walk test predicts survival in patients with idiopathic pulmonary fibrosis. *Chest* 2009; 136: 841–848.
- 50 Ramos RP, Arakaki JS, Barbosa P, *et al.* Heart rate recovery in pulmonary arterial hypertension: relationship with exercise capacity and prognosis. *Am Heart J* 2012; 163: 580–588.
- 51 Minai OA, Gudavalli R, Mummadi S, *et al.* Heart rate recovery predicts clinical worsening in patients with pulmonary arterial hypertension. *Am J Respir Crit Care Med* 2012; 185: 400–408.
- 52 Inal-Ince D, Savci S, Coplu L, *et al.* Functional capacity in severe chronic obstructive pulmonary disease. *Saudi Med J* 2005; 26: 84–89.
- 53 van Stel HF, Bogaard JM, Rijssenbeek-Nouwens LH, *et al.* Multivariable assessment of the 6-min walking test in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2001; 163: 1567–1571.
- 54 Alhamad EH. The six-minute walk test in patients with pulmonary sarcoidosis. *Ann Thorac Med* 2009; 4: 60–64.
- 55 Spruit MA, Watkins ML, Edwards LD, *et al.* Determinants of poor 6-min walking distance in patients with COPD: the ECLIPSE cohort. *Respir Med* 2010; 104: 849–857.
- 56 Callens E, Graba S, Gillet-Juvin K, *et al.* Measurement of dynamic hyperinflation after a 6-minute walk test in patients with COPD. *Chest* 2009; 136: 1466–1472.
- 57 Nishiyama O, Taniguchi H, Kondoh Y, *et al.* Dyspnoea at 6-min walk test in idiopathic pulmonary fibrosis: comparison with COPD. *Respir Med* 2007; 101: 833–838.

- 58 Gallego MC, Samaniego J, Alonso J, *et al.* Disnea en la EPOC: relacion de la escala MRC con la disnea inducida en las pruebas de marcha y de ejercicio cardiopulmonar maximo [Dyspnea in COPD: relation to the MRC scale with dyspnea induced by walking and cardiopulmonary stress testing]. *Arch Bronconeumol* 2002; 38: 112–116.
- 59 Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; 14: 377–381.
- 60 Annegarn J, Spruit MA, Savelberg HH, *et al.* Differences in walking pattern during 6-min walk test between patients with COPD and healthy subjects. *PLoS One* 2012; 7: e37329.
- 61 Ziegler B, Rovedder PM, Oliveira CL, *et al.* Repeatability of the 6-minute walk test in adolescents and adults with cystic fibrosis. *Respir Care* 2010; 55: 1020–1025.
- 62 Gagnon P, Maltais F, Bouyer L, *et al.* Distal leg muscle function in patients with COPD. *COPD* 2013; 10: 235–242.
- 63 Chuang ML, Lin IF, Wasserman K. The body weight-walking distance product as related to lung function, anaerobic threshold and peak $V'O_2$ in COPD patients. *Respir Med* 2001; 95: 618–626.
- 64 Carter R, Holiday DB, Nwasuruba C, *et al.* 6-minute walk work for assessment of functional capacity in patients with COPD. *Chest* 2003; 123: 1408–1415.
- 65 Puhan MA, Mador MJ, Held U, *et al.* Interpretation of treatment changes in 6-minute walk distance in patients with COPD. *Eur Respir J* 2008; 32: 637–643.
- 66 Puhan MA, Chandra D, Mosenifar Z, *et al.* The minimal important difference of exercise tests in severe COPD. *Eur Respir J* 2011; 37: 784–790.
- 67 Polkey MI, Spruit MA, Edwards LD, *et al.* Six-minute-walk test in chronic obstructive pulmonary disease: minimal clinically important difference for death or hospitalization. *Am J Respir Crit Care Med* 2013; 187: 382–386.
- 68 Holland AE, Hill CJ, Conron M, *et al.* Small changes in six-minute walk distance are important in diffuse parenchymal lung disease. *Respir Med* 2009; 103: 1430–1435.
- 69 Holland AE, Hill CJ, Rasekaba T, *et al.* Updating the minimal important difference for six-minute walk distance in patients with chronic obstructive pulmonary disease. *Arch Phys Med Rehabil* 2010; 91: 221–225.
- 70 Lacasse Y, Goldstein R, Lasserson TJ, *et al.* Pulmonary rehabilitation for chronic obstructive pulmonary disease. *Cochrane Database Syst Rev* 2006; 4: CD003793.
- 71 Puhan M, Scharplatz M, Troosters T, *et al.* Pulmonary rehabilitation following exacerbations of chronic obstructive pulmonary disease. *Cochrane Database Syst Rev* 2009; 1: CD005305.
- 72 Holland A, Hill C. Physical training for interstitial lung disease. *Cochrane Database Syst Rev* 2008; 4: CD006322.
- 73 Liu C, Chen J, Gao Y, *et al.* Endothelin receptor antagonists for pulmonary arterial hypertension. *Cochrane Database Syst Rev* 2009; 3: CD004434.
- 74 Britto RR, Probst VS, de Andrade AF, *et al.* Reference equations for the six-minute walk distance based on a Brazilian multicenter study. *Braz J Phys Ther* 2013; 17: 556–563.
- 75 Palange P, Forte S, Onorati P, *et al.* Ventilatory and metabolic adaptations to walking and cycling in patients with COPD. *J Appl Physiol* 2000; 88: 1715–1720.
- 76 Zainuldin R, Mackey MG, Alison JA. Prescription of walking exercise intensity from the incremental shuttle walk test in people with chronic obstructive pulmonary disease. *Am J Phys Med Rehabil* 2012; 91: 592–600.
- 77 Revill SM, Morgan MD, Singh SJ, *et al.* The endurance shuttle walk: a new field test for the assessment of endurance capacity in chronic obstructive pulmonary disease. *Thorax* 1999; 54: 213–222.
- 78 Campo LA, Chilingaryan G, Berg K, *et al.* Validity and reliability of the modified shuttle walk test in patients with chronic obstructive pulmonary disease. *Arch Phys Med Rehabil* 2006; 87: 918–922.
- 79 Eiser N, Willsher D, Doré CJ. Reliability, repeatability and sensitivity to change of externally and self-paced walking tests in COPD patients. *Respir Med* 2003; 97: 407–414.
- 80 Dyer F, Marriner P, Cheema K, *et al.* Is a practice incremental shuttle walk test really necessary? *Chron Respir Dis* 2011; 8: 201–205.
- 81 McKeough ZJ, Leung RW, Alison JA. Shuttle walk tests as outcome measures: are two incremental shuttle walk tests and two endurance shuttle walk tests necessary? *Am J Phys Med Rehabil* 2011; 90: 35–39.
- 82 Revill SM, Williams J, Sewell L, *et al.* Within-day repeatability of the endurance shuttle walk test. *Physiotherapy* 2009; 95: 140–143.
- 83 Emtner MI, Arnardottir HR, Hallin R, *et al.* Walking distance is a predictor of exacerbations in patients with chronic obstructive pulmonary disease. *Respir Med* 2007; 101: 1037–1040.
- 84 Ringbaek T, Martinez G, Brøndum E, *et al.* Shuttle walking test as predictor of survival in chronic obstructive pulmonary disease patients enrolled in a rehabilitation program. *J Cardiopulm Rehabil Prev* 2010; 30: 409–414.
- 85 Williams JE, Green RH, Warrington V, *et al.* Development of the i-BODE: validation of the incremental shuttle walking test within the BODE index. *Respir Med* 2012; 106: 390–396.
- 86 Sandland CJ, Morgan MD, Singh SJ. Detecting oxygen desaturation in patients with COPD: incremental *versus* endurance shuttle walking. *Respir Med* 2008; 102: 1148–1152.
- 87 Laude EA, Duffy NC, Baveystock C, *et al.* The effect of helium and oxygen on exercise performance in chronic obstructive pulmonary disease: a randomized crossover trial. *Am J Respir Crit Care Med* 2006; 173: 865–870.
- 88 Morales FJ, Montemayor T, Martinez A. Shuttle *versus* six-minute walk test in the prediction of outcome in chronic heart failure. *Int J Cardiol* 2000; 76: 101–105.
- 89 Jolly K, Taylor RS, Lip GY, *et al.* Reproducibility and safety of the incremental shuttle walking test for cardiac rehabilitation. *Int J Cardiol* 2008; 125: 144–145.
- 90 Evans RA, Singh SJ, Collier R, *et al.* Generic, symptom based, exercise rehabilitation; integrating patients with COPD and heart failure. *Respir Med* 2010; 104: 1473–1481.
- 91 Singh SJ, Jones PW, Evans R, *et al.* Minimum clinically important improvement for the incremental shuttle walking test. *Thorax* 2008; 63: 775–777.
- 92 Dodd JW, Hogg L, Nolan J, *et al.* The COPD assessment test (CAT): response to pulmonary rehabilitation. A multicentre, prospective study. *Thorax* 2011; 66: 425–429.
- 93 Pepin V, Laviolette L, Brouillard C, *et al.* Significance of changes in endurance shuttle walking performance. *Thorax* 2011; 66: 115–120.
- 94 Pepin V, Saey D, Whittom F, *et al.* Walking *versus* cycling: sensitivity to bronchodilation in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2005; 172: 1517–1522.
- 95 Pepin V, Brodeur J, Lacasse Y, *et al.* Six-minute walking *versus* shuttle walking: responsiveness to bronchodilation in chronic obstructive pulmonary disease. *Thorax* 2007; 62: 291–298.

- 96 Brouillard C, Pepin V, Milot J, *et al.* Endurance shuttle walking test: responsiveness to salmeterol in COPD. *Eur Respir J* 2008; 31: 579–584.
- 97 Dyer CA, Singh SJ, Stockley RA, *et al.* The incremental shuttle walking test in elderly people with chronic airflow limitation. *Thorax* 2002; 57: 34–38.
- 98 Eaton T, Young P, Nicol K, *et al.* The endurance shuttle walking test: a responsive measure in pulmonary rehabilitation for COPD patients. *Chron Respir Dis* 2006; 3: 3–9.
- 99 Leung RW, Alison JA, McKeough ZJ, *et al.* Ground walk training improves functional exercise capacity more than cycle training in people with chronic obstructive pulmonary disease (COPD): a randomised trial. *J Physiother* 2010; 56: 105–112.
- 100 Revill SM, Noor MZ, Butcher G, *et al.* The endurance shuttle walk test: an alternative to the six-minute walk test for the assessment of ambulatory oxygen. *Chron Respir Dis* 2010; 7: 239–245.
- 101 Jürgensen SP, Antunes LC, Tanni SE, *et al.* The incremental shuttle walk test in older Brazilian adults. *Respiration* 2011; 81: 223–228.
- 102 Probst VS, Hernandez NA, Teixeira DC, *et al.* Reference values for the incremental shuttle walking test. *Respir Med* 2012; 106: 243–248.
- 103 Harrison SL, Greening NJ, Houchen-Wolloff L, *et al.* Age-specific normal values for the incremental shuttle walk test in a healthy British population. *J Cardiopulm Rehabil Prev* 2013; 33: 309–313.
- 104 Onorati P, Antonucci R, Valli G, *et al.* Non-invasive evaluation of gas exchange during a shuttle walking test vs a 6-min walking test to assess exercise tolerance in COPD patients. *Eur J Appl Physiol* 2003; 89: 331–336.
- 105 Turner SE, Eastwood PR, Cecins NM, *et al.* Physiologic responses to incremental and self-paced exercise in COPD: a comparison of three tests. *Chest* 2004; 126: 766–773.
- 106 Casas A, Vilaro J, Rabinovich R, *et al.* Encouraged 6-min walking test indicates maximum sustainable exercise in COPD patients. *Chest* 2005; 128: 55–61.
- 107 McNamara RJ, McKeough ZJ, McKenzie DK, *et al.* Water-based exercise in COPD with physical comorbidities: a randomised controlled trial. *Eur Respir J* 2013; 41: 1284–1291.
- 108 American Thoracic Society, American College of Chest Physicians. ATS/ACCP Statement on cardiopulmonary exercise testing. *Am J Respir Crit Care Med* 2003; 167: 211–277.
- 109 Um SW, Yoo CG, Kim YW, *et al.* The combination of tiotropium and budesonide in the treatment of chronic obstructive pulmonary disease. *J Korean Med Sci* 2007; 22: 839–845.
- 110 Oga T, Nishimura K, Tsukino M, *et al.* The effects of oxitropium bromide on exercise performance in patients with stable chronic obstructive pulmonary disease. A comparison of three different exercise tests. *Am J Respir Crit Care Med* 2000; 161: 1897–1901.
- 111 Hallstrand TS, Boitano LJ, Johnson WC, *et al.* The timed walk test as a measure of severity and survival in idiopathic pulmonary fibrosis. *Eur Respir J* 2005; 25: 96–103.
- 112 Spruit MA, Singh SJ, Garvey C, *et al.* An official American Thoracic Society/European Respiratory Society statement: key concepts and advances in pulmonary rehabilitation. *Am J Respir Crit Care Med* 2013; 188: e13–e64.
- 113 Singh SJ, Morgan MD, Scott S, *et al.* Development of a shuttle walking test of disability in patients with chronic airways obstruction. *Thorax* 1992; 47: 1019–1024.
- 114 Singh SJ, Morgan MD, Hardman AE, *et al.* Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. *Eur Respir J* 1994; 7: 2016–2020.
- 115 Hill K, Dolmage TE, Woon L, *et al.* A simple method to derive speed for the endurance shuttle walk test. *Respir Med* 2012; 106: 1665–1670.
- 116 Takigawa N, Tada A, Soda R, *et al.* Distance and oxygen desaturation in 6-min walk test predict prognosis in COPD patients. *Respir Med* 2007; 101: 561–567.
- 117 Lama VN, Flaherty KR, Toews GB, *et al.* Prognostic value of desaturation during a 6-minute walk test in idiopathic interstitial pneumonia. *Am J Respir Crit Care Med* 2003; 168: 1084–1090.
- 118 Paciocco G, Martinez FJ, Bossone E, *et al.* Oxygen desaturation on the six-minute walk test and mortality in untreated primary pulmonary hypertension. *Eur Respir J* 2001; 17: 647–652.
- 119 Villalba WO, Sampaio-Barros PD, Pereira MC, *et al.* Six-minute walk test for the evaluation of pulmonary disease severity in scleroderma patients. *Chest* 2007; 131: 217–222.