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Reproducibility of step tests in patients with bronchiectasis

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ABSTRACT | **Background:** The step test has been used to assess exercise capacity in patients with chronic respiratory disease; however, its use has not been described with regard to patients with bronchiectasis (BCT). **Objective:** This study assessed the reliability of the Chester step test (CST) and the modified incremental step test (MIST) and also correlated these tests with pulmonary function, heart rate (HR), and distance walked during the 6-min walk test (6-MWT). **Method:** On separate days, 17 patients randomly underwent two CSTs, two MISTs, and two 6-MWTs. Number of steps (NOSs), HR, and perceived exertion were recorded immediately before and after these tests. **Results:** NOSs were similar across CSTs (124±65 and 125±67) and MISTs (158±83 and 156±76). Differences were not found across the CSTs and MISTs with regard to HR (138±25 bpm and 136±27 bpm), SpO_2 (91±5% and 91±3%), perceived exertion (dyspnea=4 [3-5] and 4 [2-4.5]) and fatigue (4 [2-6] and 4 [3-5]). The CST was significantly briefer than the MIST (6.0±2.2 min and 8.6±3.0 min) and had fewer associated NOS (125±67 and 158±83). NOSs were correlated with FEV1, the 6-MWD, and HR for both tests. **Conclusions:** The CST and MIST are reliable in patients with BCT. Patients tolerated the MIST more than the CST. Better lung function and 6-MWT scores predicted the greater NOSs and greater peak HR.

Keywords: physical therapy; bronchiectasis; stress test; step test.

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Introduction

Bronchiectasis (BCT) is a chronic lung disease characterized by the abnormal and irreversible dilatation of the bronchi that causes chronic productive cough and recurrent infections[1]. The anatomical distortion of the conducting airways reduces lung function, which is most commonly diagnosed by airflow limitation[2]. Dyspnea and fatigue are the predominant symptoms in patients with BCT and reduce exercise tolerance[3,4].

Field tests that evaluate physical capacity, such as the 6-min walk test (6-MWT), the shuttle test (ShT), and the step test (ST)[5-6], are widely used in practice due to their ease of implementation, low cost, and representativeness of daily activities[7]. Although reference values and clinically important differences have been established for the 6-MWT and ShT[8,9], the ST has often been used for patients with chronic respiratory diseases[10]. The advantage of the ST over walking tests is its portability, which facilitates its use in any environment. The pace of the ST is dictated by auditory stimuli, which favors isoload analyses (same number of steps [NOSs]/min) with revaluations of individuals after interventions. In this context, the Chester Step Test (CST), which was designed to estimate aerobic capacity in healthy participants[11-13], has also been used among patients with pulmonary disease[14-16]. However, the CST is a strenuous protocol because fewer than half of patients in recovery from severe acute respiratory syndrome are able to complete the test[14]. Furthermore, only 22% of patients with chronic obstructive pulmonary disease (COPD) are able to complete up to three of the five stages of the CST[16]. In light of these data, our group adapted the CST to reduce the initial rate to 10 steps/min and introduce increments of up to a step every 30 seconds throughout the test[17]. Compared with the CST, the modified incremental step test (MIST) results in increased exercise tolerance and has a similar duration to the 6-MWT and ShT among patients with COPD[18].

The use of step tests has not been documented among patients with BCT, whose primary functional limitation is a decrease in exercise capacity. This study assessed the reliability of the CST and MIST among patients with BCT and correlated performance

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between these tests with pulmonary function, cardiac stress, and functional capacity.

Method

This transversal study used non-probabilistic sampling from the Physical Therapy Clinic. The study was approved by the Research Ethics Committee of the Irmandade da Santa Casa de Misericórdia de São Paulo-SP (ISCMSP; # 367/10), Brazil. All volunteers signed an informed consent form before the evaluations began.

The inclusion criteria ensured that the patients had clinical and radiological diagnoses of (non-CF) BCT. These patients were clinically stable (no changes in medication, dyspnea, or secretion over the 4 weeks prior to the study) who had resting normoexemia. Participants who smoked, had other respiratory diseases (i.e., asthma, COPD, cystic fibrosis, or tuberculosis), or an inability to comprehend the test protocol were excluded from the study. In addition, patients undergoing pulmonary rehabilitation or physical therapy were not included.

Protocol

On separate days, 24 hours apart, two CSTs and MISTs each were performed, separated by 30 min of rest. The testing order was randomized by drawing lots from sealed opaque envelopes containing a card that indicated "CST" or "MIST". Each card corresponded to the test to be performed on the first visit; the other test would be conducted on the subsequent visit. Patients performed the 6-MWT on a separate day.

Evaluations

Spirometry

Spirometry was performed on the first evaluation day using the established recommendations[19] and the CPF System™ (MedGraphics Corporation® St. Paul, MN, USA). The following variables were recorded: forced vital capacity (FVC), forced expiratory volume over 1 second (FEV_1), and the relationship between them (FEV_1/FVC). The results were expressed as absolute values and percentages of the predictions[19].

CST

The CST was performed on a 20-cm step. Previously recorded auditory stimuli on a CD dictated the pace of the trial using the following sequence: 15 steps/min (Stage 1), 20 steps/min (Stage 2), 25 steps/min (Stage 3), 30 steps/min (Stage 4), and 35 steps/min (Stage 5)[11]. Each stage lasted 2 min for a total of 10 min of testing. Before beginning the CST (and at every min during the test) heart rate (HR) and pulse oximetric saturation (SpO_2) were recorded using pulse oximetry (9500, Nonin, Plymouth, Minnesota). HR was expressed in absolute terms and as a percentage of the maximum predicted by the following equation: 220-age. Perceived effort for dyspnea (Borg D) and fatigue in the lower limbs (Borg LL) was recorded before and immediately after the CST using the modified Borg scale[20]; blood pressure was also measured at these times. The patient or the physical therapist discontinued the test due to symptoms of dyspnea, fatigue, or both, when the patient was unable to maintain the pace required at each stage, when SpO_2 was <88%, or some combination therein. The outcome was the NOSs.

MIST

The MIST was conducted using the same protocol described for the CST; however, it was initiated at a rate of 10 steps/min, with increments of one step every 30 seconds as described above[17]. The parameters and criteria for discontinuation described for the CST were applied for the MIST.

The test with the highest NOSs for both the CST and MIST was correlated with the other variables and compared between tests.

Six-min walk test (6-MWT)

Patients underwent two 6-MWTs following the recommendations of the *American Thoracic Society*[21]. The outcome was the distance traveled, and the test with the higher value was selected. The distance was expressed in absolute values and as percentages of the predicted values[22].

Data analyses

The Shapiro-Wilk test was used to confirm data normality. Parametric data were expressed as the means and standard deviations (SDs), and nonparametric data were expressed as medians and interquartile ranges. The similarity of the inter- and intra-test resting variables was evaluated using paired Student's *t*-test. To examine the intra-test (CST x CST and MIST x MIST) reliabilities of the variables at peak exercise and the NOSs, paired Student's *t*-test, intraclass correlation coefficient (ICC) with 95% confidence intervals (95% CIs), and the Bland-Altman analysis were used. Paired Student's *t*-tests were used for inter-test comparisons (best CST and best MIST) with regard to HR, SpO_2, Borg D, and Borg LL at peak exercise, test time, and NOSs. The correlation between the NOSs of the best CST or MIST and age, lung function, HR peak, and 6-MWT distance was analyzed using Pearson's correlation coefficient. The level of significance used was $p<0.05$.

Results

Twenty-two patients with BCT were recruited, but five people did not agree to participate in the study; thus, 17 patients (six men) remained. With regard to lung function, eight patients showed mild obstructive patterns, six showed moderate patterns, and three showed severe patterns. Table 1 describes the patient characteristics.

Reliability of the CST and MIST

The examiner discontinued ten CSTs (four due to drops in SpO_2), whereas the patients ended seven CSTs. In addition, the examiner discontinued seven MISTs (three due to drops in SpO_2), and the patients ended 10 MISTs. The percentage of maximum HR corresponded to 80%±10% of the predicted CST and 82%±12% of the predicted MIST.

No significant differences were observed in the resting condition between CST-1 and CST-2 with regard to HR (83±12 bpm *vs.* 84±13 bpm), SpO_2 (97%±2% *vs.* 98%±2%), Borg D (2 [0.25-2.0] *vs.* 2 [0-2]), and Borg LL (0 [0-2] *vs.* 1 [0-2]). Similarly, no differences were observed between MIST-1 and MIST-2 with regard to HR (78±13 bpm *vs.* 82±13 bpm), SpO_2 (96%±2% *vs.* 96%±2%), Borg D (2 [0.5-2] *vs.* 0.5 [0-2]), and Borg LL (2 [0-2] *vs.* 1 [0-2.5]).

The peak and performance data (NOSs and time) for the CST and MIST are shown in Table 2; no significant differences were observed for any of the intra-test variables. The mean differences between CST-1 and CST-2 and between MIST-1 and MIST-2 were small for all variables (Table 2). A Bland-Altman analysis revealed that the mean difference in the NOSs between the first and second CSTs was 0.17 steps/min (95% CIs=–19.8 to 19.5 steps; Figure 1A). The mean difference for the MIST was 1.0 step/min (95% CIs=–56.8 to 58.8 steps; Figure 1B). The higher CIs for the MIST in the Bland-Altman analysis are attributable to a patient who achieved 200 steps on average but showed a difference of approximately 100 steps between MIST-1 and MIST-2 (Figure 1B). A second Bland-Altman analysis without this individual revealed CIs between -24 and 34.4 steps.

Performance comparison between the CST and MIST

The inter-test analysis of the best CST result versus the best MIST result revealed differences in test time (6.1±2.2 min and 8.8±2.8 min, $P<0.001$) and NOSs (128±64 steps and 166±78 steps; $P<0.001$). No differences were observed with regard to HR at peak exercise between the CST and MIST (138±25 bpm and 136±27 bpm, $p=0.41$), SpO_2 (91±5% and 91±3%, $p=0.19$), perceived exertion for dyspnea (4 [3-5] and 4 [2-4.5], $P=1.00$), or fatigue (4 [2-6] and 4 [3-5]; $p=0.51$). When the scores for dyspnea and fatigue were corrected based on the time for each test, we observed higher values for the CST (0.86 [0.35 to 1.09] and 0.62 [0.45 to 1.09]; $p=0.001$) compared with the MIST (0.43 [0.26 to 0.72] and 0.50 [0.29 to 0.72], $p=0.026$).

Correlation between performance on the CST and MIST

A correlation was found between $FEV_1$1 (L) and the distance covered in the 6-MWT, which matched that of the comparison between the CST and MIST with regard to NOSs (Figure 2). NOS and HR at peak test were correlated for both the CST ($r=0.74$, $p=0.001$) and MIST ($r=0.85$, $p\leq 0.001$), and NOS and age were negatively correlated according to the CST ($r=-0.61$, $p=0.009$) and MIST ($r=-0.64$, $p=0.005$).

Discussion

This study demonstrates that the CST and MIST are reliable among patients with BCT. This finding was demonstrated by the similarity in HR, SPO_2, and NOSs as well as the perception of dyspnea and fatigue scores at peak exercise between tests conducted on the same day among the weaker patients. The NOSs for both the CST and MIST showed strong correlations with FEV_1, the 6-MWT, and HR at peak exercise.

Table 1. Participants.

	Mean±SD (n=17)
Age, years	52±17
BMI, kg/m^2	23.7±4.8
FVC, L (% predicted)	2.4±0.7 (77±19.2)
FEV_1, L (% predicted)	1.5±0.6 (61±22.0)
FEV_1/FVC, L	60±10
6-MWT, m (% predicted)	522±152 (95±23)

BMI: body mass index; FVC: forced vital capacity; FEV_1: forced expiratory volume at first second; 6-MWT; 6-min walking test.

Table 2. Variables at peak exercise for the CST and MIST.

	CST-1	CST-2	ICC (CI 95%)*	MD±SD	MIST-1	MIST-2	ICC (95% CIs)*	MD±SD
HR, bpm	137±25	134±13	0.88 (0.66-0.96)	2.8±15	137±25	134±13	0.99 (0.96-1.00)	–2.9±6
SpO_2, %	91±2	91±4	0.91 (0.74-0.97)	0.4±2.3	91±5	91±3	0.92 (0.79-0.97)	–0.1±1.7
NOSs	124±65	125±67	0.99 (0.98-1.00)	–0.2±10	158±83	156±76	0.97 (0.90-0.99)	1.3±2.9
Time, min	5.9±2.2	6.0±2.2	0.99 (0.94-1.00)	–0.03±0.4	8.6±3.0	8.5±2.7	0.97 (0.92-0.99)	0.01±1.0
Borg D	4 (3-5)	4 (3-6)	0.96 (0.89-0.99)	-	4 (3-5)	4 (2-5)	0.87 (0.65-0.95)	-
Borg Leg	4 (2-6)	4 (3-5)	0.86 (0.60-0.95)	-	4 (3-5)	4 (3-5)	0.77 (0.35-0.92)	-

HR: heart rate; SpO_2: pulse oximetric saturation, NOSs: number of steps, Borg D: dyspnea score, Borg leg: leg effort score; ICC: intraclass correlation coefficient; 95% CIs: 95% confidence intervals; MD: mean difference; SD: standard deviation of differences. * $P<0.05$ for all ICCs.

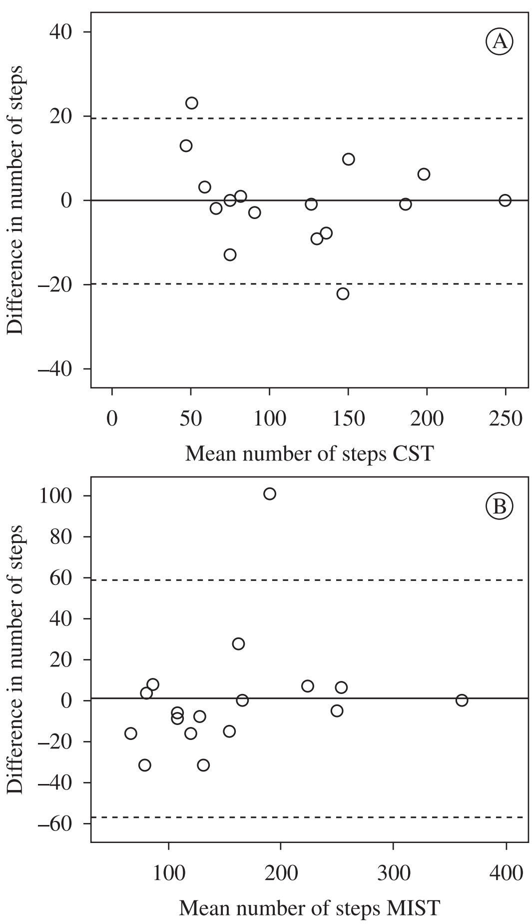

Figure 1. Bland-Altman graphical analysis of NOSs in the CST (Panel A) and MIST (Panel B). The solid horizontal line represents the mean of the differences, and the dotted lines represent the 95% confidence intervals.

Patients with BCT showed better tolerance of the MIST given the greater NOSs and the longer test duration compared with the CST.

The reliability of the different step tests has been studied among patients with idiopathic pulmonary fibrosis[23], COPD[16], asthma[24], or cystic fibrosis[25]. Although Swinburn et al.[26] observed great variation between the four step tests conducted on patients with COPD, most studies have found the opposite (i.e., little variation between the step tests among patients with chronic lung disease[16,23-25]). In patients with COPD, the CST was highly reliable for tests conducted on the same day[16], with an ICC of 0.99 (95% CIs=0.97 to 0.99) for NOSs. Balfour-Lynn et al.[25] evaluated an externally dictated (30 steps/min) 3-min step test (15-cm steps) among a subgroup of individuals with cystic fibrosis (n=12) on different days. They found that this test was reliable with regard to the evaluation of SpO_2, HR, dyspnea perception, and NOSs in 11 of 12 individuals. Tancredi et al.[24] studied children with asthma by comparing two 3-min step tests conducted on a single 30-cm step at a pace of 30 steps/min across different days. These authors did not find differences in maximal HR (191±4.6 bpm and 192±5.0 bpm) or a drop in FEV_1 (12.8±5.9% and 12.1±5.9%).

The reliability of the CST and MIST corroborate these authors' findings, and this study confirmed these results in patients with BCT; however, the Bland-Altman analysis revealed that the MIST showed a large confidence interval (–56.8 to 58.8 steps). We believe that the CST demonstrated greater reliability because its increments are more substantial (five steps) and acute throughout the test, which makes the patient perceive the exertion more quickly[27], limiting the test to similar times. Moreover, the MIST has finer increments, which minimizes the magnitude of symptoms and contributes to greater variation in NOSs at implementation. Importantly, however, the Bland-Altman analysis revealed that the majority of patients who performed the MIST showed a difference between ± 20 steps (Figure 1B), and this variation was similar to the Bland-Altman CIs for the CST.

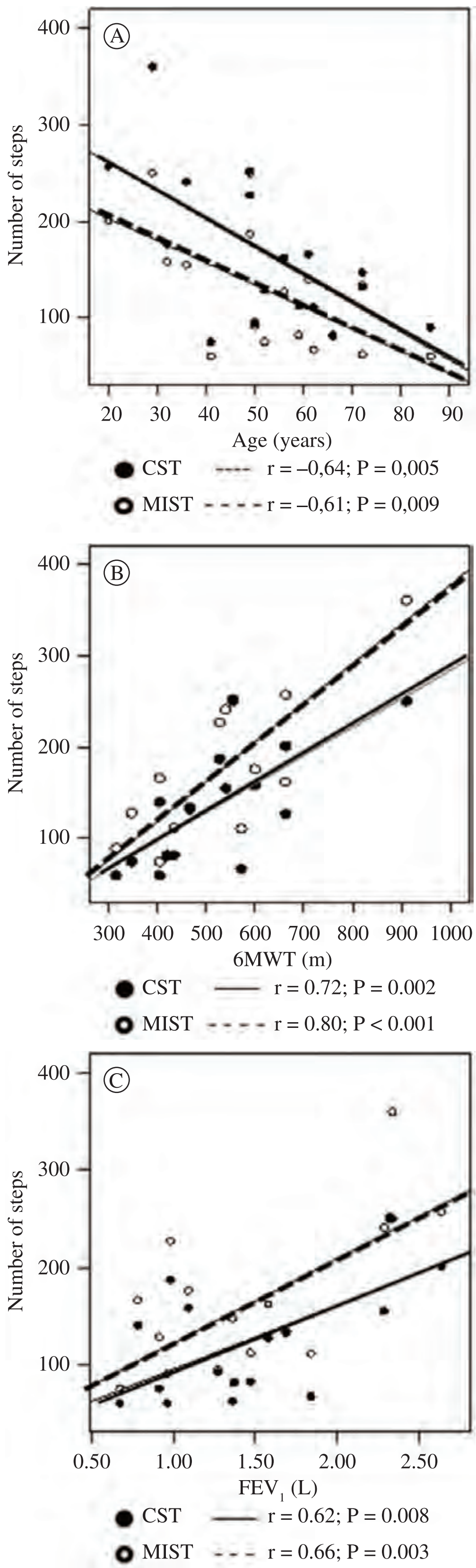

Figure 2. Correlation between the NOSs and age, 6-MWT, and FEV_1 for the CST and MIST.

To our knowledge, this study is the first to compare two types of incremental step tests among patients with BCT. In the present study, the execution time of the CST was approximately 30% briefer than that of the MIST. The decreased load on the MIST, represented by fewer NOSs at the beginning of the test and smaller increments at each stage, allowed patients to maintain their activity for longer with similar values of HR as well as perceptions of dyspnea and fatigue in the lower limbs at peak exercise compared with the CST. Again, the load increment standard affects exercise duration; that is, larger increments predict shorter test times. However, the HR, ventilation values, and peak exercise symptom scores are independent of the protocol used[27-29]. Despite presenting different times, cardiopulmonary responses at peak exercise were similar for the MIST and CST among patients with BCT. Given that performance on both tests was limited by symptoms or the inability to keep pace, patients discontinued the test at similar intensities. This finding was confirmed by the equivalent percentages of maximal HR in the CST and MIST (80±10% and 82±12%, respectively).

The mean test time for patients with BCT was 8 min for the MIST and 6 min for the CST, although the latter test was limited to 10 min. Incremental exercise test durations should be between 8 and 12 min[30]; therefore, the MIST test time was satisfactory to functionally assess patients with BCT. When comparing the performance of patients with BCT and those with COPD[16] on the CST, we observed that the former patients performed the test for a longer duration. This result might be attributed to differences in age (i.e., our patients were younger than those with COPD [52±17 years *vs.* 70±9 years, respectively]) and reduced lung function (FEV_1=61%±22% of predicted *vs.* 46%±15% of predicted, respectively).

A moderate correlation was observed between the CST and MIST with regard to FEV_1, which indicates that poorer lung function predicts weaker performances on both tests. Airway obstruction (as expressed by a reduction in FEV_1) implies decreased lung capacity, which limits physical activities. A weaker correlation was observed between NOSs and FEV_1 among patients with COPD (r=0.43)[16]. This result might be due to the greater lung function impairment among patients with COPD (FEV_1=46%±15% of predicted)[16] compared with that observed among those with BCT who were evaluated in this study (FEV_1=60%±10% of predicted).

Peak HR was strongly correlated with the NOSs climbed in both the CST and MIST. This result was expected because the increase in cardiac output during exercise fundamentally depends on increasing

HR to the maximum predicted for age given that systolic ejection volume stabilizes quickly[30]. This result also explains the negative correlation between age and performance on the step tests because cardiac output (CO) tends to decrease with age, primarily due to a decrease in maximum predicted HR[31]. In other words, because cardiac output is the product of HR multiplied by systolic ejection volume, the decrease in maximum HR predicted by age reduces CO, thereby decreasing exercise performance.

Finally, the 6-MWT was strongly correlated with the CST and MIST, which provides evidence that these tests represent functional capacity. In this context, the step test might be an alternative to assess functional capacity in patients with chronic lung disease, particularly where little space is available to perform walking tests.

This study demonstrated alternative clinical field tests (CST and MIST) that, in addition to being as inexpensive as the 6-MWT and ShT, can be used by physical therapists to assess patient functional capacity in outpatient units, clinics, and patients' homes. Furthermore, we compared two types of step tests never before documented in patients with BCT, and our results suggest that the MIST is more appropriate due to its finer increments, which allow patients to continue the test for a longer amount of time, thereby providing a sufficient amount of data to analyze a high intensity test[32,33]. Because neither step test was accompanied by the measurement of expired gases nor compared with the gold standard (maximal cardiopulmonary exercise testing performed on a treadmill or cycle ergometer), we cannot determine whether the CST and MIST are maximal tests. Undoubtedly, both step tests have incremental profiles because the intensity of exercise (NOSs per min in the case of step tests) is gradually increased. However, incremental tests are not the only way of determining maximal responses to exercise among patients with chronic lung disease. In this context, Troosters et al.[34] demonstrated that the VO_2 peak and HR expressed as percentage of the predicted value (82%±9% and 85%±9%, respectively) was similar between the 6-MWT (1.40±0.29 L/min) and the maximum incremental test on a cycle ergometer (1.41±0.18 L/min)[34]. Casas et al.[35] corroborated these findings by demonstrating that patients with COPD achieved 90% of the VO_2 observed in a maximal test on a cycle ergometer from the third minute of the 6-MWT. In addition, Turner et al.[36] did not find significant differences in HR at the peak of the 6-MWT (81.6%±11.4% of predicted), the ShT (79%±12.3% of predicted), and a cycle ergometer (79.4%±9.4% of predicted). Studies of patients with COPD, a disease similar to BCT, have been previously cited because exercise tests have not been compared in this population. Swinburn et al.[26] found that the VO_2 at peak exercise in a step test was superior to that observed for the cycle ergometer and 6-MWT. Interestingly, Swinburn et al.[26] described a constant-load-type step test because its pace was maintained at 15 steps/min; however, this step test cannot be considered submaximal because it revealed a higher oxygen consumption at peak exercise. Our group found a similar result among patients with idiopathic pulmonary fibrosis, in which the 6-min step test with the patient-determined pace accounted for 90% of the VO_2 obtained in the maximal incremental test on a cycle ergometer[23].

Therefore, walk and step tests determined the maximum responses in patients with COPD and those with idiopathic pulmonary fibrosis. Using equipment to measure expired gases was not possible in this study; therefore, we are unable to conclude whether our patients reached maximum oxygen consumption. This result contrasts with the gold standard (incremental on treadmill or cycle ergometer) because determining whether the test is maximal or submaximal is only possible when accounting for the HR criterion at peak exercise. However, based on the high percentage of maximum HR observed in both tests in this study (which were similar to those found in studies of patients with COPD comparing walk tests [6-MWT and ShT]) with maximal tests), we infer that the CST and MIST represent maximum exertion.

Because the MIST can determine HR, it can be used for exercise prescription and help clinicians to determine the stage that the patient has reached, thereby assisting in the patient's prescription and monitoring. Nevertheless, specific studies are needed to determine whether the MIST has enough sensitivity for use as a prescribed exercise.

Although we evaluated a limited number of patients, the narrow confidence intervals and small mean differences in our observed variables demonstrate excellent test reliability, meeting the central objective of the study. Assessing exhaled gases during testing would add information about oxygen and carbon dioxide production as well as ventilation at peak exercise. However, the equipment required to obtain these variables is expensive, and the variables in the present study are those most commonly used by physical therapists in clinical practice. Because walk tests are most commonly used to assess functional capacity in patients with chronic lung disease, future studies should be performed for patients with BCT to allow comparison with step tests regarding exertion outcomes (VO_2, HR, and blood pressure) and symptoms (dyspnea and fatigue).

In conclusion, CST and MIST are reliable in individuals diagnosed with BCT, and these patients show greater tolerance of the MIST. Better lung function and 6-MWT distance predict better step test performance, and patients achieve higher HRs at peak exercise.

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