Chester Step Test in Patients With COPD: Reliability and Correlation With Pulmonary Function Test Results

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BACKGROUND: The 5-stage Chester step test assesses aerobic capacity in healthy subjects. It has not been tested in patients with COPD. OBJECTIVE: To determine the reliability of the Chester step test in patients with COPD and correlation with pulmonary function test and exercise test results. METHODS: Thirty-two patients (mean ± SD FEV_1 46 ± 15% of predicted) undertook 2 Chester step tests and two 6-min walk tests, on different days, in random order. A subgroup of 11 patients performed incremental cycle ergometry. RESULTS: Thirty-one patients performed stage 1 of the Chester step test. Nineteen patients performed stage 2 of the Chester step test. The number of steps was highly reproducible: 66 ± 41 steps vs 68 ± 41 steps. There was no difference in heart rate or S_{pO_2} between the 2 Chester step tests at the peak of exercise or at the end of each stage. There was a significant correlation between number of steps and FEV_1 (r = 0.43, P = .02), and 6-min walk distance (r = 0.60, P = .001). Heart rate increased according to advanced stages of the Chester step test, up to 81 ± 13% of predicted. There was a significant correlation between number of steps and peak heart rate (r = 0.55, P = .001). In the 11 patients who performed the incremental cycling test there was a significant correlation between number of steps and peak work load (r = 0.69, P = .02). In the 6 patients in whom oxygen uptake could be estimated from the Chester step test, oxygen uptake was higher than that measured at the peak of the cycling test (30.8 ± 5.1 mL/kg/min vs 17.4 ± 4.5 mL/kg/min, respectively, P = .001). CONCLUSIONS: Despite being highly reproducible, the Chester step test had a very short duration in patients with COPD. The number of steps incremented in each stage seems to be too large for these patients. An adaptation of the Chester step test should be considered for patients with COPD. *Key words: Chester step test; COPD; reliability; exercise test.* [Respir Care 2011;56(7):995–1001. © 2011 Daedalus Enterprises]

Introduction

Apart from pulmonary impairment, COPD leads to peripheral muscle dysfunction.[1] The combination of pulmonary and muscular disturbances contributes to reduced exercise capacity.[2] The 6-min walk test and shuttle test are commonly used to assess functional capacity in patients with COPD. The step test is widely used in healthy subjects, and several step test protocols have been adapted to study various outcomes in cardiopulmonary diseases.[3-13] The advantage of the step test over the 6-min walk test or

shuttle test is that the step test requires less space and therefore can be conducted in settings such as an intensive care unit, a physician's office, or at a home-based or in-patient rehabilitation program.

A wide variety of step tests have been described, with different cadences (self-paced or externally paced), step heights, and test durations. Because of the huge possibilities for adaptation, step tests can be used to assess physical capacity in patients with varied health status. The Chester step test was originally designed to assess aerobic capacity in healthy subjects,[14] and was recently used to predict maximum oxygen uptake ($\dot{V}_{O_2}$) and to evaluate the effectiveness of an exercise training program in patients with severe acute respiratory syndrome,[12,13] but it has not been tested in COPD patients. In patients with COPD we evaluated the reliability of the Chester step test and its correlation with pulmonary function and exercise test results.

Methods

This study was approved by our institutional ethics committee, and all subjects gave written informed consent prior to inclusion.

Patients

We studied 32 (3 female) consecutive patients diagnosed with COPD. The inclusion criteria were $FEV_1 < 70\%$ of predicted, and clinical stability (no change in medication dosage in the preceding 4 weeks). We excluded patients with other pulmonary diseases (bronchiectasis and cystic fibrosis) or orthopedic or neurological conditions.

Protocol

On 2 different days, at least 48 hours apart, patients were randomized to perform either two 6-min walk tests (30 min rest between the tests) or two Chester step tests (30 min rest period between the tests).

Spirometry

We classified the severity of obstruction on spirometry results.[15] Spirometry was performed at each visit, before the exercise tests, to check for similar pulmonary function on the 2 test days. Spirometry (CPF System, Medical Graphics, St Paul, Minnesota) was performed before and after bronchodilator (400 μg of inhaled albuterol), per the American Thoracic Society/European Respiratory Society statement.[16] We report the absolute and percent-of-predicted forced vital capacity and FEV_1.[17]

Body Mass Index

We categorized the subjects into the following body mass index (BMI) categories: underweight < 20.0 kg/m^2, normal weight 20.0–24.9 kg/m^2, overweight > 25.0–29.9 kg/m^2, and obese > 30.0 kg/m^2.[18]

6-Minute Walk Test

Patients performed two 6-min walk distance according to American Thoracic Society recommendations.[19] We measured heart rate (Polar Precision Performance, Kemple, Finland) and S_{pO_2} (9500, Nonin, Plymouth, Minnesota) at rest before the test, half way through the test (3 min), and at the end of the test (6 min). We assessed dyspnea and leg fatigue at rest and immediately after finishing the test, with the modified Borg scale.[20] If the patient was unable to walk for the full 6 minutes of the test, we recorded heart rate, S_{pO_2}, and walk distance at the point they stopped walking. We interrupted the test if S_{pO_2} dropped below 88%, then after a 30-min rest period, we repeated the test with supplemental oxygen from a portable oxygen cylinder carried by the physiotherapist. We titrated the supplemental oxygen to maintain $S_{pO_2} \geq 88\%$. We report the absolute and percent-of-predicted 6-min walk distances.[21] We considered a 6-min walk distance $< 82\%$ of predicted below normal.[21] We selected the test with the higher 6-min walk distance for correlation with the Chester step test.

Chester Step Test

The Chester step test was performed on a 20 cm tall, single-step device with no handles. The Chester step test has 5 stages, each of 2 minutes duration (total test time 10 min). The step cadence is set with a metronome, which starts at 15 steps/min and increases by 5 steps/min every 2 minutes: stage 1 (15 steps/min), stage 2 (20 steps/min), stage 3 (25 steps/min), stage 4 (30 steps/min), stage 5 (35 steps/min). Each subject underwent a step-test training session to determine if he or she was able to keep up the cadence set by the metronome. Before and every one minute during the training test we measured heart rate and S_{pO_2}, and the rules for supplemental oxygen were the same. The test was terminated either by the patient (because of dyspnea and/or leg fatigue) or by the physiotherapist if the patient was unable to maintain the cadence for 15 seconds. The subject scored his or her dyspnea and leg fatigue with the modified Borg scale at rest before the test and immediately after the test. The main outcome of the Chester step test is the total number of steps taken, and we recorded the test with the highest number of steps. This test was used for analyzing heart rate response during the test and for correlations with pulmonary function and exercise capacity tests. We estimated peak $\dot{V}_{O_2}$ during the Chester step

test with the Chester Step Test Calculator (Assist Creative Resources, Wrexham, United Kingdom),[22] which uses a regression line through submaximal heart-rate points that correspond to each test stage, up to a horizontal line that corresponds to the patient's predicted maximum heart rate (220 – age). A minimum of 2 exercise heart rates (ie, completing at least the first 2 stages of the Chester step test) is required. From the point that the regression line crosses the patient's predicted maximum heart rate, a perpendicular line is drawn down to the graph's X axis, which gives an estimated $\dot{V}_{O_2}$ (range 10–76 mL/kg/min). In normal subjects the accuracy of this estimate is approximately 5–15%.[23]

Cardiopulmonary Exercise Testing

A subset of 11 of the 18 patients who did not require supplemental oxygen during the step testing, did incremental exercise testing on an electromagnetically braked cycle ergometer (CPE 2000, Medical Graphics, St Paul, Minnesota), during which we measured pulmonary gas exchange (MGC-CPX, Medical Graphics Corporation, St Paul, Minnesota). We continuously increased the work rate by 5–15 watts/min so that the ramp duration was > 8 min and < 12 min. We considered a reduced aerobic capacity a peak $\dot{V}_{O_2}$ < 70% of predicted.[24] We compared the measured peak $\dot{V}_{O_2}$ during cycling to the estimated peak $\dot{V}_{O_2}$ in the Chester step test. For this part of the study we analyzed 6 patients, because to estimate $\dot{V}_{O_2}$ from the Chester step test it is necessary to complete at least the first 2 stages of the Chester step test and the subject must be ≤ 70 years old.[21]

Statistical Analysis

We report parametric data as mean ± SD, and nonparametric as median and range values. Differences in heart rate, S_{pO_2}, and number of steps were determined via paired-t test. To determine the test/retest reliability of the measured variables between the Chester step tests we calculated the intraclass correlation coefficients with one-way analysis of variance. An intraclass correlation coefficient of 0.80–1.0 is considered excellent reliability, 0.60–0.79 is good reliability, and < 0.60 is low reliability. We also used the Bland-Altman method to analyze the reliability of the number of steps. We used the step test with the higher number of steps for the correlations analysis. We calculated the Pearson correlation coefficients to analyze the relationship between number of steps and FEV_1, forced vital capacity, heart rate and oxygen saturation at peak exercise during the Chester step test, and 6-min walk distance. We used the paired t test to compare the estimated and measured $\dot{V}_{O_2}$ values. The probability of type 1 error was set at 5% (P < .05). The analyses were performed with statistics software (SPSS 14.0, SPSS, Chicago, Illinois).

Table 1. Subjects ($n = 32$)

	Mean ± SD	Percent Predicted
Age (y)	69.9 ± 9.0	NA
BMI (kg/m^2)	25.9 ± 15.1	NA
FEV$_1$ (L)	1.2 ± 0.4	46 ± 15
FVC (L)	2.8 ± 0.8	81 ± 16
FEV$_1$/FVC	43.6 ± 10.4	NA
6-min walk distance (m)	398 ± 110	69 ± 20
Cycle Ergometry ($n = 11$)		
Peak work load (watts)	61.2 ± 24.7	43 ± 14
Peak $\dot{V}_{O_2}$ (L/min)	1.15 ± 0.38	56 ± 13

NA = not applicable
BMI = body mass index
FVC = forced vital capacity
$\dot{V}_{O_2}$ = oxygen uptake

Results

As expected, all the subjects had reduced pulmonary function (Table 1). Twenty-seven patients had moderate to severe obstruction, and 5 had very severe obstruction. One subject was underweight, 17 were normal weight, 5 were overweight, and 9 were obese. Twenty patients had a 6-min walk distance < 82% of predicted. Peak aerobic capacity was below the predicted values: 8 out of the 11 cycle ergometry subjects had peak $\dot{V}_{O_2}$ < 70% of predicted.

Reliability of the Chester Step Test

The subjects presented similar pulmonary function between the first and the second Chester step test: FEV$_1$ 1.18 ± 0.36 L vs 1.17 ± 0.36 L, respectively, and forced vital capacity 2.84 ± 0.77 L vs 2.90 ± 0.77 L, respectively. Between the tests there was no significant difference in heart rate, S_{pO_2}, dyspnea score, or leg fatigue score measured at rest (Table 2).

All the patients could follow the cadence imposed during the Chester step test. Eighteen of the 32 patients needed supplemental oxygen (4 ± 2 L/min). Considering the best performance on the Chester step test, 31 patients completed stage 1, 19 completed stage 2, 7 completed stage 3, and 1 patient completed stage 4 and the first minute of stage 5. Twelve patients had the test interrupted by the physiotherapist because the patient could not maintain the cadence. Twenty patients asked to stop the test because of dyspnea (2 patients), leg fatigue (8 patients), or dyspnea plus leg fatigue (10 patients). Table 2 shows the median dyspnea and leg fatigue scores at peak exercise during the step test. A similar number of patients performed best on

Table 2. Chester Step Test Results

	Chester Step Test 1	Chester Step Test 2	Intraclass Correlation Coefficient*	95% CI of Intraclass Correlation Coefficient
At Rest Before Test	($n = 32$)	($n = 32$)		
Heart rate (beats/min)	86 ± 14	83 ± 13	0.88	0.78–0.94
S_{pO_2} (%)	95 ± 2	95 ± 2	0.85	0.77–0.93
Dyspnea score, median (range)	0.5 (0–2)	0.5 (0–3)	0.92	0.84–0.96
Leg fatigue score, median (range)	0.5 (0–3)	0.5 (0–3)	0.91	0.81–0.96
Stage 1	($n = 31$)	($n = 31$)		
Heart rate (beats/min)	109 ± 15	108 ± 16	0.94	0.88–0.96
S_{pO_2} (%)	92 ± 4	92 ± 4	0.83	0.65–0.92
Stage 2	($n = 17$)	($n = 19$)		
Heart rate (beats/min)	119 ± 13	116 ± 14	0.94	0.84–0.98
S_{pO_2} (%)	92 ± 3	91 ± 4	0.80	0.42–0.93
Stage 3	($n = 7$)	($n = 7$)		
Heart rate (beats/min)	136 ± 8	132 ± 11	0.87	0.77–0.87
S_{pO_2} (%)	94 ± 2	93 ± 2	0.95	0.65–0.99
Stage 4	($n = 1$)	($n = 1$)		
Heart rate (beats/min)	148	150	NA	NA
S_{pO_2} (%)	95	92	NA	NA
Peak Step-Test Exercise	($n = 32$)	($n = 32$)		
Heart Rate				
(beats/min)	120 ± 17	121 ± 20	0.95	0.89–0.97
(% predicted)	80 ± 10	80 ± 13	0.95	NA
S_{pO_2} (%)	92 ± 4	91 ± 4	0.91	0.81–0.96
Dyspnea, median (range)	4 (1–10)	4 (0–9)	0.90	0.79–0.95
Leg fatigue, median (range)	4 (2–10)	5 (0–9)	0.86	0.71–0.94
Exercise time (s)	229 ± 106	228 ± 113	0.98	0.98–0.99
Number of steps	66 ± 41	68 ± 41	0.99	0.97–0.99

± values are mean ± SD.
* All the intraclass correlation coefficients are statistically significant.
NA = not applicable

the first versus the second Chester step test (16 and 15 patients, respectively).

Between the 2 Chester step tests there were no significant differences in heart rate or S_{pO_2} at peak step-test exercise or at the end of each stage, and the reliability analysis revealed high intraclass correlation coefficients (see Table 2). The Bland-Altman analysis (Fig. 1) of the number of steps in the first versus the second Chester step test showed a mean difference of −1.1 steps/min (limits of agreement −20.2 to 17.9 steps).

There was a moderate correlation between number of steps and FEV_1 (r = 0.43, P = .02), and a stronger relationship between number of steps and 6-min walk distance (r = 0.60, P = .001). Heart rate increased progressively in the stages of the Chester step test, to 81 ± 13% of predicted at peak exercise (see Table 2). There was a significant correlation between number of steps and peak heart rate (r = 0.55, P = .001). There was no significant correlation between number of steps and S_{pO_2}.
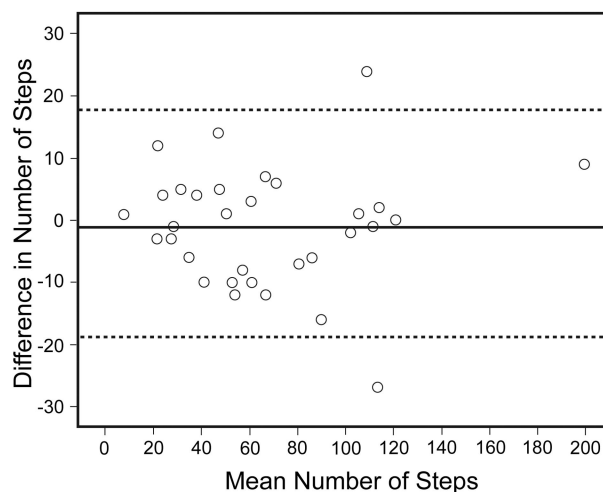

Fig. 1. Bland-Altman plot of number of steps versus between-test difference in number of steps. The solid horizontal line represents the mean bias. The dashed horizontal lines represent 1.96 standard deviations.

In the 11 patients (FEV_1 45 ± 17% of predicted) who performed the incremental cycling test the peak work load was 61.2 ± 24.7 watts (43 ± 14% of predicted), and there was a significant correlation with the number of steps (r = 0.69, P = .02). Only 6 of the cycling-test patients (FEV_1 41 ± 16% of predicted) met the criteria required to estimate $\dot{V}_{O_2}$ from the Chester step test, and it was higher than the measured $\dot{V}_{O_2}$ at the peak of the cycling test (30.8 ± 5.1 mL/kg/min vs 17.4 ± 4.5 mL/kg/min, respectively, P = .001).

Discussion

The similarity between Chester step test trials for heart rate and S_{pO_2} at each stage and at peak exercise, total number of steps, and dyspnea and leg fatigue indicates that the Chester step test is reproducible in COPD patients, and significantly correlates with FEV_1, 6-min walk distance, and peak work load during cycling ergometry.

There have been few studies of step tests in patients with chronic pulmonary diseases. In patients with COPD, Swinburn et al[4] found large inter-subject differences in performance (range 14–126 steps), which is much greater than we observed in our study (limits of agreement −20.2 to 17.9 steps). Increments in the work rate during the Chester step test might improve the reproducibility, because the work intensity influences symptom magnitude (dyspnea and fatigue) much more than does the test duration.[25] The cadence changes during the Chester step test determine the increase in the work intensity, which precipitates the perceived exertion, leading patients to discontinue the test at a similar stage to that achieved in the previous test. Patients with cystic fibrosis[5] and exercise-induced asthma[7] showed better reproducibility in a step test than we observed. Both of the latter studies used a 3-min step test, and though some of the children could continue the test, it was interrupted when the established end-time was reached, and we suspect that the short test duration probably contributed to the excellent reproducibility.

Despite the differences between the step test used by Swinburn et al and the Chester step test (step height 25 cm vs 20 cm, respectively, and cadence constant vs incremental, respectively), the patients were able to tolerate very similar and short test durations. A previous study found that stair climbing resulted in prolonged lung hyperinflation, a higher blood lactate, and greater dyspnea than walking in patients with severe COPD.[26] The findings were similar in a comparison of cycling and walking.[27] In the present study the physiologic mechanisms underlying the very short duration of the Chester step test in patients with COPD could not be explored because gas-exchange variables were not measured.

The strength of correlation between number of steps and pulmonary function was moderate and very similar to the results from comparisons of 6-min walk distance and shuttle test.[28-30] Furthermore, the relationship we observed between the Chester step test steps and 6-min walk distance was comparable to the relationship previously found between 6-min walk distance and shuttle walk distance.[31] In addition, the correlation we observed between number of steps and peak work load in the cycling test (r = 0.69) was similar to that reported in studies of peak work load in the 6-min walk test versus the shuttle test.[32,33] Therefore the number of steps climbed in the Chester step test can be representative of functional performance, and, when tests that require long corridors are unfeasible, step tests may be an alternative. However, further studies are needed to establish a better incremental pattern for patients with chronic respiratory diseases, once it has been demonstrated that variations of incremental size affect exercise time in patients with COPD.[34,35] Then, when large increments are used, the test certainly will be brief. Despite the consistent results in repeated Chester step tests in our patients, we speculate that reducing the work load increment would be appropriate for patients with COPD, to achieve a total exercise time of 8–10 min, which is efficient and useful for assessing cardiopulmonary responses.[36]

We found no significant correlation between number of steps and S_{pO_2} at peak exercise. This finding may be explained by the combination of a short test time and the use of supplemental oxygen during the Chester step test. Maximum heart rate peak exercise in the Chester step test corresponded to 80% of predicted maximum, which is equivalent to that observed at peak exercise in both the 6-min walk test[33,37] and the shuttle test.[33] This result was expected, because the Chester step test is a 2-min incremental exercise test that elicits a graded cardiovascular response (see Table 2).

Based on heart rate achieved in each Chester step test stage it is possible to estimate the peak $\dot{V}_{O_2}$.[22] We found a huge difference between the estimated and measured $\dot{V}_{O_2}$. In addition to the inaccuracy inherent in estimating peak $\dot{V}_{O_2}$ from Chester step test results in healthy subjects,[38] abnormal heart-rate responses during the Chester step test can also affect this $\dot{V}_{O_2}$ estimate. Debigaré et al have found that a faster work rate increment led to a right shift of the relationship between heart rate and work rate.[34] Therefore, lower heart rates are observed during increase in work rate incremental rate.

In addition, patients with COPD presented with a slower response of heart rate during exercise than did normal subjects.[39] Although this finding has been described in cycling tests, we speculate that the same effect could be observed in step tests, especially if large increments are imposed. Even though baseline heart rate is not considered as a point in the regression line to estimate $\dot{V}_{O_2}$ from

Chester step test, a high baseline heart rate can also contribute to a low change in heart rate with exercise progression. This possible overestimation of $\dot{V}_{O_2}$ from Chester step test was also speculated for patients with severe acute respiratory syndrome explained by a higher baseline heart rate and delayed increase in heart rate during the test.[13]

Limitations

First, our patients completed just 2 Chester step tests, and a similar number of patients achieved their best Chester step test score in their first and second test. Therefore, we do not know how many Chester step tests are necessary to achieve the best performance. Second, the sample size we used to compare the estimated and measured $\dot{V}_{O_2}$ was small ($n = 6$). In addition, patients were not able to complete all the stages of the Chester step test, which may have limited the accuracy of the peak $\dot{V}_{O_2}$ estimates. A larger-sample study with measurement of pulmonary gas exchange in patients with COPD is needed to verify the cardiopulmonary responses during the Chester step test. Finally, we used the number of steps as an estimation of work performed in the Chester step test,[8] but the use of this outcome as a surrogate for work must be validated for the Chester step test in patients with COPD.

Conclusions

The Chester step test is highly reproducible in patients with COPD, but the Chester step test seems to be a difficult protocol for patients with chronic respiratory disease, probably because of an initial cadence that is too high and a work-load increment that is too large for these patients. Therefore, an adaptation of the Chester step test for patients with COPD should be tested.

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