RESPIRATORY CARE Paper in Press. Published on June 25, 2013 as DOI: 10.4187/respcare.02331

Title Page

Manuscript Category: Original Research

Title: Pulmonary Function Test Quality in the Elderly

A Comparison with Younger Adults

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Text

Abstract

Introduction: Elderly patients may be at greater risk for misdiagnosis and inappropriate treatment as a consequence of pulmonary function test (PFT) underutilization and tests being conducted with low quality expectations. This study sought to determine if elderly patients are able to achieve both spirometry and diffusion capacity (DL_{CO}) quality scores comparable to a younger adult population. Methods: retrospective review of pulmonary function data over a 22 month period. A list of every patient age ≥ 80 years (elderly group) and ages 40-50 years (control group) tested during the time period was compiled. The quality of spirometry and DL_{CO} testing were examined. Results: 92.6% (139/150) of elderly group and 91.5% (163/178) of control group spirometry tests satisfied all American Thoracic Society/European Respiratory Society (ATS/ERS) acceptability and reproducibility criteria ($p = 0.84$). 84.9% (96/113) of elderly group and 88.5% (108/122) of control group DL_{CO} tests satisfied all ATS/ERS acceptability and reproducibility criteria ($p = 0.45$). Conclusion: Elderly patients referred to a hospital-based PFT lab can be expected to achieve spirometry and DL_{CO} quality scores comparable to younger adult patients.

Key words: pulmonary function tests; spirometry; diffusing capacity; test quality

Introduction

Elderly patients with cognitive impairment and apraxia have difficulty performing spirometry correctly.[1-2] However, several studies have shown that most elderly patients can produce quality spirometry data.[3-7] There is limited and conflicting data on the effect of age on the ability to perform diffusion capacity of the lung for carbon monoxide

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(DL_{CO}) correctly.[8-9] Elderly patients are at risk for misdiagnosis and inappropriate treatment of respiratory disease[10-11] which may be compounded by pulmonary function test (PFT) underutilization and the inappropriate acceptance of suboptimal test quality due to low performance expectations. This study sought to determine if elderly patients referred to a hospital-based pulmonary function laboratory are able to achieve both spirometry and DL_{CO} quality scores comparable to a younger adult population.

Methods

Retrospective review of pulmonary function data over a 22 month period (June 2011-March 2013) in a hospital-based pulmonary function laboratory (St. Joseph Hospital, Nashua New Hampshire). The St. Joseph Hospital Institutional Review Board approved this study. Using the "research query tools" function of the Morgan Scientific ComPAS pulmonary function system (Morgan Scientific, Haverhill Massachusetts) a list of every patient age ≥ 80 years (elderly group) tested during the time period was compiled. Every patient age 40-50 years tested during the same time frame served as a control. Demographic data was collected and the quality of spirometry and DL_{CO} testing were examined. The mean and median of the "percent of predicted" values and the percentage of test results below the lower limits of normal were recorded for DL_{CO}, forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1) and the ratio of FEV_1 to FVC. Our laboratory uses Global Lung Function Initiative (age range 3-95 years)[12] and Cotes[13] predicted equations for spirometry and DL_{CO}, respectively. American Thoracic Society/European Respiratory Society (ATS/ERS) quality standards were used to judge individual test quality.[14-15] The Morgan Scientific ComPAS system provides an on-screen display of effort-by-effort test acceptability and reproducibility as

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well as a more detailed grading of test quality based on ATS/ERS quality standards[14-15] (see figure 1.) In addition to computerized quality scoring, each pulmonary function test was examined in detail by the chief technologist to confirm the accuracy of computer grading. FVC and FEV_1 were graded on an A-B-C-D-F quality scale as described in the Global Lungs Initiative Phase 2 Pilot Study[16] (see table 1). During this time period the laboratory was staffed by 3 technologists. Two technologists had > 20 years of testing experience and the remaining technologist had 5 years of testing experience. The chief technologist of the laboratory is a registered pulmonary function technologist. The laboratory's quality assurance program includes on-going technologist performance surveillance and monthly and quarterly technologist performance feedback.[17-18] Examination of the quality control records from the study period revealed no issues in terms of pneumotach or gas analyzer malfunction. Moreover, no out-of-control conditions were identified from the review of biologic control testing records.

Statistical Analysis

Commercially available software was used for statistical computations (Prism 4, Stat Mate 2.0, GraphPad Software Inc. San Diego, CA). Differences in categorical data were examined with Fisher's exact test. Differences in continuous data were examined with a student t-test for unpaired means and the Mann-Whitney test for unpaired medians. Data are reported as mean ± SD or median with inter-quartile range. Post hoc power analysis of test success for this 22 month sample was performed. A two-tailed p value of < 0.05 was considered significant.

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Results

During the study period 150 elderly subjects attempted 150 spirometry and 113 DL_{CO} tests. During the same time frame 178 control subjects attempted 178 spirometry and 122 DL_{CO} tests. Demographic data is listed in table 2. The elderly group had a lower FVC and FEV_1, expressed as a percent of predicted but not as a proportion of values below the lower limit of normal. The percentage of FEV_1/FVC values below the lower limit of normal was not different between groups. DL_{CO} was lower in the elderly group both as a percent of predicted and as a proportion of values below the lower limit of normal.

Spirometry Quality

In the elderly group 92.6% (139/150) of spirometry tests satisfied all ATS/ERS acceptability and reproducibility criteria (grade A).[14] Of the 11 tests that failed to meet all ATS/ERS performance standards, 3 had both FVC and FEV_1 grades ≥ C. When these test are included, 94.6% of tests produced clinically meaningful FVC and FEV_1 data.[16] Five tests had both FVC and FEV1 scores < C; 3 had an FEV1 grade ≥ C coupled with an FVC grade < C. The most common reason for test failure were the inability to exhale for ≥ 6 seconds and an extrapolated volume > 5% of the FVC or > 150 ml.

In the control group 91.5% (163/178) of spirometry tests satisfied all ATS/ERS acceptability and reproducibility criteria (grade A).[14] Of the 15 tests that failed to meet all ATS/ERS performance standards, 1 test had both FVC and FEV_1 grades ≥ C. When this test is included, 92.1% of tests produced clinically meaningful FVC and FEV_1 data.[16] Three tests had both FVC and FEV1 scores < C; 10 tests had FEV1 grades ≥ C coupled with FVC grades < C, and 1 test had an FVC grade ≥ C coupled with an FEV1 grade < C.

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The most common reason for test failure were the inability to exhale for ≥ 6 seconds , extrapolated volume > 5% of the FVC or > 150 ml, and failure to reach the peak expiratory flow within 1.2 seconds. There was no difference in spirometry test quality between the groups (p = .84; see table 3). Post-hoc analysis revealed that this comparison had 80% power to detect an 8% difference in success with a significance level of 0.05 (two-tailed p).

DL_{CO} Quality

In the elderly group 84.9% (96/113) of tests satisfied all ATS/ERS acceptability and reproducibility criteria.[15] Of the 17 DL_{CO} tests that failed to satisfy all ATS/ERS criteria, one test was performed correctly and was reproducible but only failed to satisfy acceptability criteria because severe airflow obstruction precluded capture of the alveolar sample within 4 seconds. When this test is included, 85.8% of DL_{CO} tests were performed correctly and provided reproducible values.

In the control group 88.5% (108/122) of tests satisfied all ATS/ERS acceptability and reproducibility criteria.[15] Of the 14 DL_{CO} tests that failed to satisfy all ATS/ERS criteria, two tests were performed correctly and were reproducible but only failed to satisfy acceptability criteria because severe airflow obstruction precluded capture of the alveolar sample within 4 seconds. When these tests are included, 90.2% of DL_{CO} tests were performed correctly and provided reproducible values. There was no difference in DL_{CO} test quality between the groups (p = .45; see table 3). Post hoc analysis revealed that this comparison had 80% power to detect a 12% difference in success with a significance level of 0.05 (two-tailed p).

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Discussion

Undiagnosed respiratory disease and the underutilization of pulmonary function testing in elderly patients is common and the impact of undiagnosed disease is substantial.[11,19] Indeed, undiagnosed COPD in ageing individuals has a significant effect on health-related quality of life.[20] Dow et al[10] reported that 84% of older patients with untreated asthma were found to moderate to severe disease after spirometry testing was performed. In addition, elderly patients may more frequently be subjected to a poorly conducted PFT if the technologist has a preconceived notion that elderly patients are less likely to be able to perform testing correctly.

Diminished cognitive function and apraxia (inability to perform a motor activity from thought) in elderly patients with neurologic impairment can certainly make meaningful PFT data very difficult or impossible to obtain. Allen and Baxter[1] studied the strength of cognitive tests to predict the ability of elderly subjects to perform spirometry correctly. Lower scores on the Mini Mental State Examination (overall cognition) and difficulty drawing intersecting pentagons were predictive of spirometry test failure. Interestingly, tests of executive function were found to be less predictive of outcome. Carvalhaes-Neto et al[2] assessed the ability of elderly institutionalized subjects with cognitive dysfunction to perform spirometry testing. Only 41% of subjects were able to perform spirometry correctly and lower scores on the Mini Mental State Examination test correlated with rates of spirometry failure.

While it is clear that elderly patients with marked cognitive impairment and apraxia are less likely to perform spirometry (forced or slow[21]) correctly, most elderly patients without severe cognitive impairment are able to produce quality spirometry data.

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Sherman and colleagues[3] assessed the ability of 65 elderly subjects with only mild cognitive impairment to perform spirometry. Of the group, 87.6% of subjects were able to produce acceptable spirometry data. The Salute Respiratoria Nell' Anziano[4] (SARA [Respiratory Health in the Elderly]) collected spirometry data from patients with ages ranging from 65-100 years using mostly inexperienced technicians. The SARA investigators reported that 78% of all subjects produced 3 acceptable spirometry efforts.[4] Pezzoli et al[5] studied 715 elderly patients with respiratory symptoms and found that 81.8% of patients were able to perform spirometry correctly. These and a number of other studies[6-7, 21] clearly show that cognitive function and not age itself is predictive of successful or unsuccessful spirometry testing in elderly patients. Indeed, there is no data to suggest that younger patients with severe cognitive impairment would perform spirometry any better than elderly patients with similar cognitive deficits. There is far less data regarding the effect of age on the ability to perform DL_{CO} correctly. In a general population study conducted in the 1980s, Welle et al[8] found that only 67% of adult subjects could perform DL_{CO} testing correctly and that younger age was an independent predictor of test failure. The Welle study differs from current practice because the minimally acceptable ratio of inspired vital capacity to FVC was 0.9, higher than the current standard 0.85.[15] It is also notable that one technologist with unspecified experience performed 96% of the tests. Neas and Schwartz[9] examined DL_{CO} data from the first National Health and Nutrition Examination Survey (1971-1975). Missing DL_{CO} data (it is assumed that the patient could not perform the test properly) occurred in 40% of patients age 65-74 years and in 22% of subjects age 25-54 years. In contrast to the current study, both of these studies used data collected from older instrumentation

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without quality control software and analyzed data approximately 10 and 20 years after it was originally collected, respectively.

In the present study 92.6% and 84.9% of elderly patients were able to perform both spirometry and DL_{CO} tests to the satisfaction of ATS/ERS acceptability and reproducibility standards respectively.[14-15] Despite a higher prevalence of age-adjusted abnormal lung function (DL_{CO}), there was no difference in the percentage of high quality tests between the elderly group (median age 83 years) and a much younger control group (median age 46 years). This study differs from many studies of spirometry quality in the elderly because this study used data from patients 80 years and older while several previously published studies used samples from patients aged 65 years and older.[3-6]

A contributing factor to the high quality scores documented in this study is our laboratory's use of a quality assurance program which includes on-going technologist performance surveillance and monthly and quarterly technologist performance feedback. The goal of our laboratory is that 90% of all tests meet ATS/ERS acceptability and reproducibility standards.[22] Data supporting technologist performance feedback originated from the Lung Health Study.[18] Enright and the Lung Health Study Research Group showed that technologist performance was vacillating until a program of technologist monitoring and feedback was instituted. The SARA study utilized a technologist monitoring and feedback program and as cited earlier, was able to obtain quality spirometry data from 78% of elderly patients even with inexperienced technologists.[4] More recently, Borg and colleagues[23] documented that adherence to spirometry quality standards increased from 61% to 92% in a hospital-based PFT lab after a technologist performance feedback program was initiated. While technologist

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monitoring and feedback is an ATS/ERS quality assurance recommendation,[17] as few as 30% of laboratories may have such a program in place.[24]

PFTs should be conducted with the goal of collecting data of the highest quality; however, spirometry data with less than "grade A" quality should not necessarily be classified as invalid and go unreported. Hankinson et al[16] examined the impact of FVC and FEV_1 quality grades (see table 1) on predicted reference equations. Only FVC and FEV_1 data with scores of D and F negatively impacted the formulation of predicted values and lower limits of normal. Average z-scores for FVC and FEV_1 were similar from data with A-C quality scores. In clinical practice, spirometry tests with grades B and C, while not perfect, in most cases should be reported. In the current study, the percentage of spirometry tests in the elderly group characterized as valid and meaningful increased from 92.6% to 94.6% with the inclusion of tests with B and C quality scores.

The present study has limitations; the pool of subjects comes from a population with little diversity in terms of culture and race. However, there is no reason to believe that the same level of PFT quality shouldn't be achievable in any community. In a study of 6,193 DL_{CO} tests, Punjabi and colleagues[25] found no association between race and test reproducibility. Differences in regional PFT referral practices could have a significant impact on test quality. A laboratory which services physicians who regularly refer patients with significant cognitive impairment and apraxia may experience less success when testing an elderly population. In addition, this study reports data from a community hospital laboratory with three experienced staff members; results might differ in larger laboratories with more diversity in terms of technologist experience and skill level. Similar studies in different communities and laboratory settings are warranted.

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It has been suggested that the use the Cotes[13] DL_{CO} reference equations may not be ideal for older patients, since like most DL_{CO} reference equations, there was limited sampling of elderly subjects.[26] Garcia-Rio et al[26] published predicted equations for DL_{CO} in patients ages 65-85 years and a comparison with the Cotes[13] equation suggested that the Cotes equation underestimates DL_{CO} in elderly men and women. However, we have found the Cotes equations to function well in our patient population. The DL_{CO} equation that agreed the best with the Garcia-Rio equation was the equations of Crapo and Morris[27] which we believe overestimates DL_{CO} in both our young and elderly patients. It is noteworthy that the Garcia-Rio[26] and Crapo[27] equations were generated using data collected at altitudes of 655 meters and 1,400 meters above sea level respectively while Nashua New Hampshire has an altitude of 50 meters above sea level. DL_{CO} is well known to be positively correlated with altitude.[28]

Conclusions

The overwhelming majority of elderly patients referred to a hospital-based pulmonary function laboratory can perform spirometry and DL_{CO} testing to the satisfaction of ATS/ERS acceptability and reproducibility standards. Elderly patients are capable of producing quality spirometry and DL_{CO} data comparable to younger adults. Advanced age, by itself should not discourage patient referrals for PFTs or lower expectations for a high quality test.

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Figure 1. Legend

Fig. 1. A snapshot on-screen display of test acceptability and reproducibility for spirometry (upper panel) and DL_{CO} (lower panel). The small check marks indicate effort acceptability and the large central check mark indicates effort reproducibility. (Morgan ComPAS, Morgan Scientific Inc. Haverhill, MA).

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Table 1. Quality Grades for FVC and FEV_1[16]

Quality Grades of FVC

Grade	Acceptable Efforts (#)	Repeatability (ml)
A	≥ 3	≤ 150
B	2	≤ 150
C	≥ 2	≤ 200
D	≥ 2	≤ 250
F	≤ 1	n/a

Quality Grades of FEV_1

Grade	Acceptable Efforts (#)	Repeatability (ml)
A	≥ 3	≤ 150
B	2	≤ 150
C	≥ 2	≤ 200
D	≥ 2	≤ 250
F	≤ 1	n/a

FVC = forced vital capacity

FEV_1 = forced expiratory volume in the first second

n/a = not applicable

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Table 2. Demographics

	Elderly(n = 150)	Control (n = 178)	p
Age			
Mean ± SD y	83.9 ± 3.4	45.7 ± 3.2	<0.0001
Median (IQR)	83 (81-86)	46 (43-49)	<0.0001
% Female	52 (78/150)	61.2 (109/178)	> 0.09
% Caucasian	99.3 (149/150)	94.3 (168/178)	0.01
FVC % predicted			
Mean ± SD	82.5 ± 18.31	93.1 ± 17.7	<0.0001
Median (IQR)	85 (71-94)	95 (82.5-105.5)	<0.0001
FVC < LLN (%)	21.7 (32/147)	18.2 (32/176)	0.48
FEV_1 % predicted			
Mean ± SD	76.5 ± 22.9	86.8 ± 22.0	<0.0001
Median (IQR)	79 (60-94)	89.5 (76-102)	<0.0001
FEV_1 < LLN (%)	33.3 (49/147)	28.4 (50/176)	0.39
FEV_1/FVC< LLN(%)	19.7 (29/147)	22.1 (39/176)	0.68
DL_{CO} % predicted			
Mean ± SD	55.8 ± 19.6	80.3 ± 17.4	<0.0001
Median (min-max)	56 (43-70)	81 (71.5-92)	<0.0001
DL_{CO}< LLN (%)	55.3 (57/103)	18.9 (22/116)	<0.0001

SD = standard deviation of the mean

IQR = inter-quartile range

FVC = forced vital capacity

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LLN = lower limit of normal

FEV_1 = forced expiratory volume in the first second

FEV_1/FVC = ratio of FEV_1 to FVC

DL_{CO} = diffusion capacity of the lung for carbon monoxide

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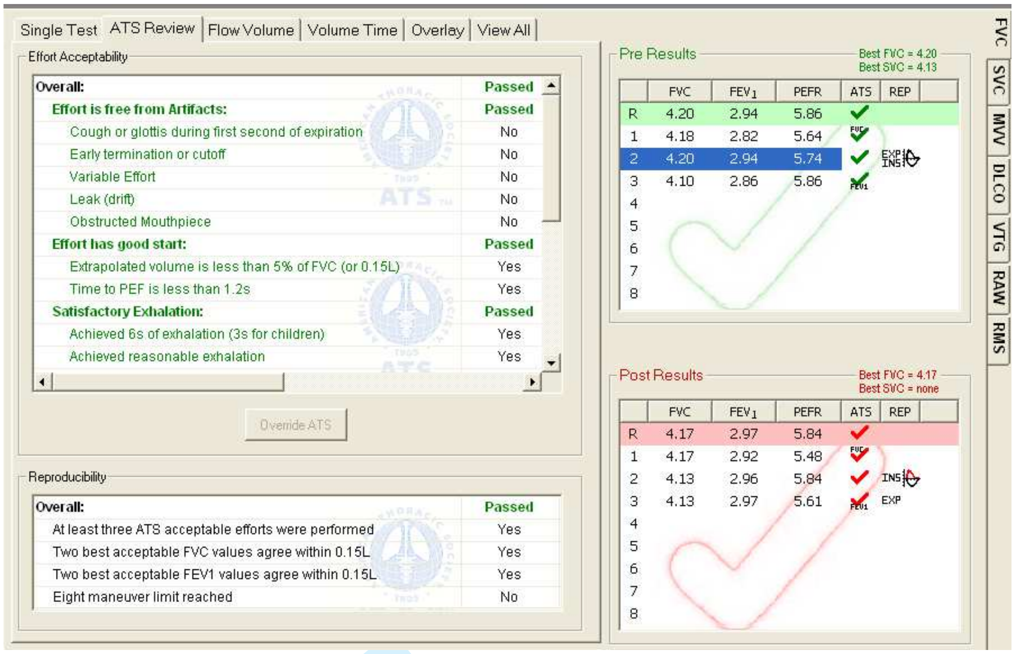
Table 3. Spirometry and DL_{CO} Quality

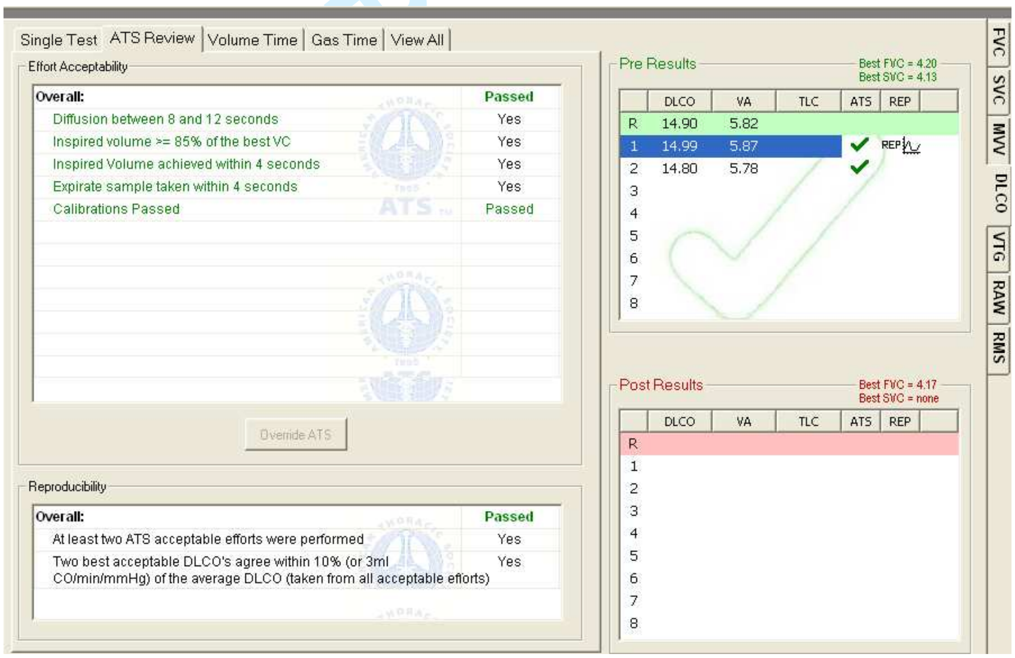
	Elderly	Control	p
Spirometry Grades			
FVC & FEV1 = A (%)	92.6 (139/150	91.5 (163/178)	.84
FVC & FEV1 ≥ C (%)	94.6 (142/150)	92.1 (164/178)	.39
DL_{CO} Quality			
Meets all standards (%)	84.9 (96/113)	88.5 (108/122)	.45
Performed correctly (%)	85.8 (97/113)	90.2 (110/122)	.32

FVC = forced vital capacity

FEV_1 = forced expiratory volume in the first second

DL_{CO} = diffusion capacity of the lung for carbon monoxide


Single Test
ATS Review
Flow Volume
Volume Time
Overlay
View All
Effort Acceptability
Overall: Passed
Effort is free from Artifacts: Passed
Cough or glottis during first second of expiration No
Early termination or cutoff No
Variable Effort No
Leak (drift) No
Obstructed Mouthpiece No
Effort has good start: Passed
Extrapolated volume is less than 5% of FVC (or 0.15L) Yes
Time to PEF is less than 1.2s Yes
Satisfactory Exhalation: Passed
Achieved 6s of exhalation (3s for children) Yes
Achieved reasonable exhalation Yes
Override ATS
Reproducibility
Overall: Passed
At least three ATS acceptable efforts were performed Yes
Two best acceptable FVC values agree within 0.15L Yes
Two best acceptable FEV1 values agree within 0.15L Yes
Eight maneuver limit reached No
Pre Results
Best FVC = 4.20
Best SVC = 4.13
FVC FEV1 PEFR ATS REP
R 4.20 2.94 5.86
1 4.18 2.82 5.64
2 4.20 2.94 5.74 EXP INS
3 4.10 2.86 5.86
4
5
6
7
8
Post Results
Best FVC = 4.17
Best SVC = none
FVC FEV1 PEFR ATS REP
R 4.17 2.97 5.84
1 4.17 2.92 5.48
2 4.13 2.96 5.84 INS
3 4.13 2.97 5.61 EXP
4
5
6
7
8
FVC
SVC
MVV
DLCO
VTG
RAW
RMS


Single Test
ATS Review
Volume Time
Gas Time
View All
Effort Acceptability
Overall: Passed
Diffusion between 8 and 12 seconds Yes
Inspired volume >= 85% of the best VC Yes
Inspired Volume achieved within 4 seconds Yes
Expirate sample taken within 4 seconds Yes
Calibrations Passed Passed
Override ATS
Reproducibility
Overall: Passed
At least two ATS acceptable efforts were performed Yes
Two best acceptable DLCO's agree within 10% (or 3ml CO/min/mmHg) of the average DLCO (taken from all acceptable efforts) Yes
Pre Results
Best FVC = 4.20
Best SVC = 4.13
DLCO VA TLC ATS REP
R 14.90 5.82
1 14.99 5.87 REP
2 14.80 5.78
3
4
5
6
7
8
Post Results
Best FVC = 4.17
Best SVC = none
DLCO VA TLC ATS REP
R
1
2
3
4
5
6
7
8
FVC
SVC
MVV
DLCO
VTG
RAW
RMS