Eur Respir J
1988, 1, 293–296

EDITORIAL

Standardization of spirometry and single breath DLCO tests

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Standards for patient care and especially for pulmonary function testing have become important world wide, especially in the United States [1, 2, 3]. Recently the American Thoracic Society (ATS) has published two new statements. One is an update of its spirometry standardization [1] and the other recommends standard techniques for the single breath diffusion capacity (transfer factor) or DLCO [2]. The 1987 ATS spirometry recommendation is an update from the 1979 document which had a great impact on the quality of equipment and testing in the United States. Standardization of spirometry took on an international flavour with the publication by the "Bulletin", in 1983, of the European Community for Coal and Steel recommendations on standardized lung function testing [4]. The ATS originally established recommendations for spirometry as part of the "Epidemiology Standardization Project" under the auspices of the Division on Lung Disease of the National Heart, Lung and Blood Institute [5]. Recently the ATS Board of Directors instructed their Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories to update the recommendations on spirometry standardization. As briefly reported in the "Bulletin" [6] the same committee was also the convener of a conference in Alta, Utah, USA in October of 1984 to develop standard methods for the single breath carbon monoxide diffusing capacity (DLCO) (transfer factor or TLCO). The Alta meeting was attended by international experts with representatives from the USA and Europe [2]. Preliminary versions of the diffusing capacity document were circulated widely and reviewed by expert groups in the USA and Europe.

Good inter-laboratory agreement has always been a goal of clinical pulmonary function testing laboratories. Strict standardization of equipment and of procedure is increasingly important as one step in improving inter-laboratory comparability. The need for standardization is greater the more complex the technique, as is the case with the DLCO measurement, since it involves measurement of volumes, time, and several gas concentrations (He, CO, O_2 and CO_2) in the inhaled mixture and the sample of alveolar gas.

Measurement of the forced vital capacity (FVC) manoeuvre with a spirometer has become a common practice in pulmonary, occupational, and general medicine. There is widely expressed attraction to the use of an inexpensive, though potentially "less accurate", spirometer in clinical practice. Such an attraction is flawed since treatment decisions must be based on the best data available. Spirometry results are used to make decisions about individual patients *e.g.*: does this patient have enough evidence of impaired lung function to preclude working at a specific job? Should steroid treatment be continued? Does this person qualify for full disability compensation on the basis of impaired lung function? Should the subject's insurance status be changed? Answers to these questions are often based on spirometric manoeuvres alone and can have a dramatic effect on a person's employment, life style, standard of living and future treatment.

Likewise, accurate results are required for epidemiological studies. Rates of improvement or deterioration of pulmonary function in relation to an environmental exposure and/or personal characteristics may be erroneous if inaccurate spirometers and methods are used. Whether obtained in a hospital-based diagnostic laboratory, or in a physician's office, the need for accurate results is imperative.

Spirometry

The spirometry recommendations include information about standardization in the following areas:

1. Equipment selection advice including suggestions about graphical displays and recorders.
2. Equipment validation methodology.
3. Equipment quality control measures.
4. Spirometry manoeuvre performance recommendations.
5. Measurement procedures including back extrapolation to determine time zero.
6. Acceptability and reproducibility of test performance criteria.
7. Suggestions about reference values and standardization of interpretation of results.
8. The importance of clinical assessment.
9. Appendices include: a) a tutorial on computerized spirometry signal processing techniques and b) copies of the 24 standard test waveforms used for spirometer testing.

The material presented here is a brief summary of the ATS recommendations. Table 1 is a summary of the equipment recommendations for spirometry. A paper record or graphical display of the spirometry signal is required and must be acceptable for one of the following purposes:

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Table 1. – Summary table of minimal recomendations for spirometry systems

Test	Range/Accuracy BTPS (*l*)	Flow range ($l \cdot s^{-1}$)	Time (s)	Resistance & back pressure	Test signal
FVC	7 *l* ±3% of reading or ±0.05 *l*, whichever is greater	0 to 12	15		24 standard waveforms
FEV_t	7 *l* ±3% of reading or ±0.5 *l*, whichever is greater	0 to 12	t	Less than 1.5 cm $H_2O \cdot l^{-1} \cdot s^{-1}$, from 0 to 12 $l \cdot s^{-1}$	24 standard waveforms
Time zero	The time point from which all FEV_t measurements are taken. Determined by back extrapolation.				
$FEF_{25-75\%}$	7 *l* ±5% of reading or ±0.2 $l \cdot s^{-1}$, whichever is greater	0 to 12	15	Same as FEV_t	24 standard waveforms
$\dot{V}$	±12 $l \cdot s^{-1}$ ±5% of reading or ±0.2 $l \cdot s^{-1}$, whichever is greater	0 to 12	15	Same as FEV_t	Manufacturer proof

$FEF_{25-75\%}$: forced mid-expiratory flow; $\dot{V}$: instantaneous gas volume flow

1. Diagnostic function

When waveforms are used for quality control or review of the forced vital capacity manoeuvre to determine if it was properly performed so that unacceptable manoeuvres can be eliminated. Minimum requirements: volume resolution 0.050 *l*, scale factor 5 $mm \cdot l^{-1}$. Flow resolution 0.20 $l \cdot s^{-1}$, scale factor 2.5 $mm \cdot l^{-1} \cdot s^{-1}$. Time resolution 20 msec, scale factor 1 $cm \cdot s^{-1}$.

2. Validation function

When waveforms are to be used to validate the spirometer system (hardware and software) for accuracy and reliability through the use of hand measurements. For example measurement of forced expiratory volume in one second (FEV_1) using the back extrapolation for measuring time zero. Minimum requirements: volume resolution 0.025 *l*, scale factor 10 $mm \cdot l^{-1}$. Flow resolution 0.10 $l \cdot s^{-1}$, scale factor 5 $mm \cdot l^{-1} \cdot s^{-1}$. Time resolution 20 msec, scale factor 2 $cm \cdot s^{-1}$.

3. Hand measurements

When waveforms must be hand measured to determine spirometry parameters in the absence and/or failure of a computer. Minimum requirements: volume resolution 0.025 *l*, scale factor 10 $mm \cdot l^{-1}$. Flow resolution 0.10 $l \, s^{-1}$, scale factor 5 $mm \cdot l^{-1} \cdot s^{-1}$. Time resolution 20 msec, scale factor 2 $cm \cdot s^{-1}$.

When a flow-volume curve is plotted or displayed, exhaled flow should be plotted upwards, and the exhaled volume towards the right. A 2:1 ratio should be maintained between flow and volume scales *e.g.*, 2 $l \cdot s^{-1}$ flow and 1 *l* of exhaled volume should be the same distance on their respective axes.

Recent testing of 57 contemporary spirometers showed that only slightly more than 50% currently meet the ATS recommendations [7]. Computer software was identified as the problem in many of the devices that failed. Equipment quality control and methods for quality improvement are included in the new recommendations. Forced vital capacity (FVC) manoeuvre performance recommendations are now made which are more detailed and clear than those of the original ATS recommendations.

Single breath diffusing capacity - DLCO or (transfer factor TLCO)

Large variations in DLCO have been observed for individual subjects presenting at different laboratories. The variation is much larger than that seen for spirometry. In addition to physiological variability there are three other sources of DLCO variability which have been identified: 1. non-standardized test technique; 2. errors in gas analysis, and 3. computational algorithm errors.

The DLCO recommendations include information about standardization in the following areas:

1. Equipment selection and maintenance recommendations.
2. Standard techniques.
3. Standard formulae and computational methods.
4. Standard patient conditions and testing methodology, including patient conditions, alveolar volume, washout volumes, alveolar sample volume, rate of inspiration and inspiratory resistance and inspired oxygen pressure and alveolar oxygen tension.
5. The number of tests, the interval between tests, the patient position during the test and the condition of the breath-hold.

Interpretation of DLCO results requires making adjustments for haemoglobin concentration, the effects of carboxyhaemoglobin, the effect of altitude, and the selection of appropriate reference equations. Table 2 summarizes the DLCO recommendations.

We hasten to emphasize that standardization is not synonymous with truth but only an attempt to improve test reproducibility. When possible, available scientific information was used by the ATS committees as a guide to making recommendations. In the absence of definitive information, especially in the DLCO

Table 2. – Summary of D_{LCO} recommendations

Analyzer & equipment	
Volume accuracy	±3% over 7 *l* range
Gas meter accuracy or linearity	±1% of full scale range
Inspiratory circuit resistance	<1.5 $cmH_2O \cdot l^{-1} \cdot s^{-1}$ at 6 $l \cdot s^{-1}$ flow
Technique factors	
Inspired volume (V_I) size	>90% of largest vital capacity
Alveolar volume (V_A) measurement	Single breath technique always. Other techniques acceptable as alternative
Alveolar dead space washout volume	0.75 to 1.0 *l*
Alveolar sample volume	0.5 to 1.0 *l* in a ≤1.0 *l* sample bag
Alveolar sample time	<3 s
Inspiratory time	90% of V_I in ≤2.5 s in normals; ≤4.0 s when severe airway obstruction presents
Fractional inspiratory oxygen F_{IO_2} (test gas F_{IO_2})	At sea level 0.21 American 0.17 Europe Altitude recommendations – adjust F_{IO_2} to give P_{IO_2}=150 mmHg or use sea level values and adjust interpretation
Number of tests	At least two "acceptable" tests
Interval between tests	≥4 min
Patient position	Seated
Condition of breath hold	Relaxed against a closed glottis or valve
Calculation factors	
Breath hold time – calculation – duration	Jones-Meade or Ogilvie (classic) 9 to 11 s
Inspired volume (V_I) deadspace	Adjust for both mechanical and anatomic deadspace (assume V_D anatomic =150 ml). Adjusted V_I=measured V_I-V_D instrument-V_D anatomic
Alveolar sample bag dead space	Adjust for effect on measured alveolar He concentration as follows: Adjusted F_AHe=measured $F_AHe \cdot (Vs\ bag/[Vs\ bag-V_D\ bag])$. Vsbag=volume of alveolar sample; Vobag=dead space of alveolar sample bag F_AHe=fractional alveolar helium;
Inspired gas conditions	Adjust to appropriate conditions (ATPS or ATPD)
CO_2 absorption prior to gas analysis	Adjust for as follows: CO_2 adjusted F_AHe=measured $F_AHe \cdot (1-F_{ACO_2})$ One may assume F_{ACO_2}=0.05: F_{ACO_2}=fractional alveolar carbon dioxide concentration
Reproducibility criteria	The two tests should be within ±10% or 3 ml $CO \cdot min^{-1} \cdot mmHg^{-1}$ whichever is larger
Gas conditions of V_A in denominator of D_L/V_A	BTPS
Interpretative recommendations	
Haemoglobin	Recommended but not mandatory. Hb adjusted D_{LCO}=observed $D_{LCO} \cdot (10.22+Hb)/1.7 \cdot Hb$ Hb=haemoglobin concentration in $gm \cdot dl^{-1}$
Carboxyhaemoglobin (COHb)	Recommended but not mandatory. COHb adjusted D_{LCO}= measured $D_{LCO} \cdot \{1.0+(\%COHb/100)\}$
Altitude	Interpretive adjustments Altitude adjusted D_{LCO}=measured D_{LCO} $\{1.0+0.0035 \cdot (P_{AO_2}-120)\}$ P_{AO_2}=alveolar sample oxygen tension. Other options given. Average adjustments may be made.

This is a simplified summary. The new ATS document gives the justification for each decision, references when possible, and alternatives when necessary.

document, some arbitrary decisions were made by consensus to allow the development of recommendations for standard technique. As further scientific information becomes available the recommendations will be updated. The DLCO recommendations are intended primarily for use on adults and may not be applicable to children.

We are excited about the ability which standardization gives laboratories world-wide to better share results. We encourage the European pulmonary community to embrace these standardization efforts and carefully validate the recommendations made. If there are errors in the recommendations or scientific information which should be brought to bear we invite constructive criticism of these recomendations. In the years to come, we must move towards world-wide pulmonary function testing standardization which will allow us to detect and evaluate subtle differences of ethnic and geographical origins in pulmonary function measurements. In the future other pulmonary function tests will be reviewed for standardization. We encourage an international approach to this process.

Copies of the two standardization documents can be obtained from: The American Thoracic Society, 1740 Broadway, New York, NY USA 10019-4374.

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