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# Pulmonary Function Testing

## Spirometry

**ATS/ERS 2005 : Standardisation of Lung Function Testing: Standardisation of the measurement of spirometry**

*V. Brusasco, R.Crapo and G. Viegi - Eur Respir J 2005; 26: 319–338*

Spirometry is a physiological test that measures how an individual inhales or exhales volumes of air as a function of time. The primary signal measured in spirometry may be volume or flow. Spirometry is invaluable as a screening test of general respiratory health in the same way that blood pressure provides important information about general cardiovascular health. In this document, the most important aspects of spirometry are the forced vital capacity (FVC), which is the volume delivered during an expiration made as forcefully and completely as possible starting from full inspiration, and the forced expiratory volume (FEV) in one second, which is the volume delivered in the first second of an FVC manoeuvre. Other spirometric variables derived from the FVC manoeuvre are also addressed.

**ERS TASK FORCE Global Lung Initiative 2012: Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations**

*Quanjer PH et al "" - Eur Respir J. 2012 Dec;40(6):1324-43.*

This study has led to the derivation of continuous equations for predicted values and age-appropriate LLN for spirometric indices from 3–95 yrs of age, based on 74,187 records from healthy nonsmoking males and females from 26 countries across five continents. Ethnic and geographic groups can be grouped under the headings Caucasian, African–American, and North and South East Asian. The GLI 2012 reference equations are a huge step forward, providing a robust reference standard to streamline the interpretation of spirometry results within and between populations worldwide.

**ACOEM 2011: Spirometry in the Occupational Health Setting**

*ACOEM (American College of Occupational and Environmental Medicine) 2011 Update.*

Spirometry, the most frequently performed pulmonary function test (PFT), is the cornerstone of occupational respiratory evaluation programs. In the occupational health setting, spirometry plays a critical role in the primary, secondary, and tertiary prevention of workplace-related lung disease. Four major topics are covered in this statement: (1) equipment performance, (2) conducting tests, (3) comparing results with reference values, and (4) evaluating results over time.

## Broncho Challenge

**ERS technical standard on bronchial challenge testing: general considerations and performance of methacholine challenge tests.**

*Coates AL, Wanger J, Cockcroft DW, Culver BH; and the Bronchoprovocation Testing Task Force. Eur Respir J. 2017 May 1;49(5).*

This international task force report updates general considerations for bronchial challenge testing and the performance of the methacholine challenge test. There are notable changes from prior recommendations in order to accommodate newer delivery devices.

**ATS 1999: Guidelines for Methacholine and Exercise Challenge Testing**

*Crapo RO et al. - Am J Respir Crit Care Med Vol 161, Pp 309-329, 2000*

This statement provides practical guidelines and suggestions for methacholine and exercise challenging testing. Specifically, it reviews indications for these challenges, details factors that influence the results, presents brief step-by-step protocols, outlines safety measures, describes proper patient preparation and procedures, provides an algorithm for calculating results, and offers guidelines for clinical interpretation of results. The details are important because methacholine and exercise challenge tests are, in effect, dose–response tests and delivery of the dose and measurement of the response must be accurate if a valid test is to be obtained. These guidelines are geared to patients who can perform good-quality spirometry tests; they are not appropriate for infants or preschool children.

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## Body Plethysmography (TGV/RAW)

**ATS/ERS 2005: Standardisation of Lung Function Testing: Standardisation of the measurement of lung volumes**

***V. Brusasco, R. Crapo and G. Viegi - Eur Respir J 2005; 26: 511-522***

The determination of FRC is the key component in the measurement of lung volumes, and can be assessed by body plethysmography, gas washout or gas dilution methods, or using radiography. The FRCpleth includes nonventilated, as well as ventilated, lung compartments, and, thus, yields higher results than the gas dilution or washout methods. The FRCpleth may be further increased by gas that is present in the abdomen. In cases of severe airflow obstruction, FRCpleth may be overestimated when panting rates are >1 Hz

**ERS 1997: Measurement of lung volumes by plethysmography**

***Coates AL, Peslin R, Rodenstein D, Stocks J. - Eur Respir J. 1997 Jun;10(6):1415-27.***

Review of the principles, practice and limitations of plethysmography, and recommend standards for the plethysmographic measure of lung volumes. These standards will include equipment specifications and measurement techniques over the age range from infancy to adulthood.

**A rapid plethysmographic method for measuring thoracic gas volume: a comparison with a nitrogen washout method for measuring functional residual capacity in normal subjects**

***Arthur B. DuBois, Stella Y. Botelho, George N. Bedell, Robert Marshall, and Julius H. Comroe, Jr. - J Clin Invest. Mar 1956; 35(3): 322–326.***

A major advantage of the new technique is that it measures the total volume of compressible gas in the thorax, whether in communication with the airway or not, and therefore should provide the basis for the quantitative measurement of non-ventilated gas

**A new method for measuring airway resistance in man using a body plethysmograph: values in normal subjects and in patients with respiratory disease**

***Arthur B. DuBois, Stella Y. Botelho, and Julius H. Comroe, Jr. - J Clin Invest. Mar 1956; 35(3): 327–335.***

This method of measuring airway resistance alone with a body plethysmograph has the following uses: a) Objective measurement of airway resistance in patients; it has the advantage of measuring one specific component of the mechanical factors in breathing, without the requirement of maximal respiratory effort on the part of the patient; b) Quantitative and objective evaluation of therapeutic procedures designed to relieve airway obstruction; c) Separate measurement of airway resistance so that tissue resistance can be determined as the difference between total resistance and airway resistance; d) Study of multiple physiological, pharmacological and environmental and pathological factors that may affect airway resistance.

## Diffusing Lung Capacity

**2017 ERS/ATS standards for single-breath carbon monoxide uptake in the lung.**

***Graham BL, Brusasco V, Burgos F, Cooper BG, Jensen R, Kendrick A, MacIntyre NR, Thompson BR, Wanger J. Eur Respir J. 2017 Jan 3;49(1).***

A joint taskforce appointed by the ERS and ATS reviewed the recent literature on the measurement of DLCO and surveyed the current technical capabilities of instrumentation being manufactured around the world. The recommendations in this document represent the consensus of the taskforce members in regard to the evidence available for various aspects of DLCO measurement.

**ATS/ERS 2005: Standardisation of Lung Function Testing: Standardisation of the single breath determination of carbon monoxide uptake in the lung**

***V. Brusasco, R.Crapo and G. Viegi - Eur Respir J 2005; 26: 720-735***

The single-breath determination of DL,CO involves measuring the uptake of CO from the lung over a breath-holding period. While it is recommended that at least two DL,CO tests should be performed, research is needed to determine the actual number of tests required to provide a reasonable estimate of average DL,CO value for a given person.

**Implementing the three –equation method of measuring single breath carbon monoxide diffusing capacity**

***Graham BL, Mink JT, Cotton DJ - Can Respir J 1996; 3 (4): 247-257***

Measurements of $DLco^{SB}$ using the three-equation method can potentially improve both the precision and the accuracy of $DLco^{SB}$ while permitting the measurement to be made from a single breath manoeuvre, which can be done eqully well by normal subjects and by patients with lung disease and which far more closely resembles normal respiration.

**ATS 1995: Single-breath carbon monoxide diffusing capacity (transfer factor). Recommendations for a standard technique--1995 update**

***American Thoracic Society. Am J Respir Crit Care Med. 1995 Dec;152(6 Pt 1):2185-98.***

Measuring an "overall" CO uptake by the single-breath technique has proved useful in assessing a variety of lung abnormalities that impair alveolar capillary gas transport. Moreover, in many diseases, the magnitude of abnormalities in DLCO has been shown to correlate with disease severity and with direct measurements of arterial blood oxygenation, especially during exercise.

**ERS 1993: Standardization of the measurement of transfer factor (diffusing capacity). Official Statement of the European Respiratory Society.**

***Cotes JE, Chinn DJ, Quanjer PH, Roca J, Yernault JC. Eur Respir J Suppl. 1993 Mar;16:41-52.***

The measurement of transfer factor (TL) usually constitutes the second stage in the assessment of lung function after the performance of spirometry and measurement of lung volume. The transfer factor is used mainly for the diagnosis and clinical management of persons with suspected or confirmed disease of the parenchyma of the lung, for example generalised emphysema, interstitial fibrosis or extrinsic allergic alveolitis.

## Nitrogen Washout (FRC)

**ATS/ERS 2013: Consensus statement for inert gas washout measurement using multiple and single breath tests**

***Robinson PD, Latzin P, Verbanck S, Hall GL, Horsley A, Gappa M, Thamrin C, Arets HG, Aurora P, Fuchs SI, King GG, Lum S, Macleod K, Paiva M, Pillow JJ, Ranganathan S, Ratjen F, Singer F, Sonnappa S, Stocks J, Subbarao P, Thompson BR, Gustafsson PM - Eur Respir J 2013; 41: 507–522.***

Marked ventilation distribution abnormalities occur in obstructive lung disease despite normal ventilatory capacity as measured by spirometry. Washout tests may provide insight into mechanisms behind abnormal ventilation distribution and localisation of pathology. MBW is particularly attractive as it uses either relaxed tidal breathing (mostly in paediatric settings) or a fixed tidal volume (usually 1 L in adults) without need for maximal effort, thereby offering feasibility in all age groups. Washout recording systems determine inspired and expired inert gas volumes, by continuously measuring inert gas concentrations synchronised with respiratory flow.

**ATS/ERS 2005: Standardisation of Lung Function Testing: Standardisation of the measurement of lung volumes**

***V. Brusasco, R. Crapo and G. Viegi - Eur Respir J 2005; 26: 511-522***

The gas dilution/washout methods are widely used because they are simple to perform and the instrumentation is relatively inexpensive.

If measurements of N2 concentration are made indirectly by subtracting measurements of O2 and CO2, the accuracy, drift and linearity characteristics of the O2 and CO2 analysers should result in indirect calculations of N2, with comparable performance characteristics to the direct measurements of N2 specified previously.

**ATS/ERS 1997: Multiple-breath nitrogen washout techniques: including measurements with patients on ventilators**

***Newth CJ, Enright P, Johnson RL - Eur Respir J. 1997 Sep;10(9):2174-85.***

If the primary interest is alveolar growth and development, or the assessment of total gas volume in a child with airway disease, then plethysmography may be the most relevant technique. By contrast, if one is interested in the accessible, rather than compressible lung volume, i.e. the functional lung volume available for gas exchange, then one of the gas dilution techniques may be more appropriate.

Under certain circumstances, it may also be rational to use both techniques, depending on the clinical entity that is to be measured. For example, in lung cysts and lobar emphysema, use of both FRC measured in an infant plethysmograph (FRCpleth) and a gas dilution technique will allow quantification of the amount of gas trapped. Except in the smallest of infants, sedation is required for each technique up to the age of 4–6 yrs.

The open circuit, multiple-breath nitrogen washout test used to measure lung volumes should not be confused with the single-breath nitrogen test, also known as the "closing volume" test. Both tests use similar instrumentation, both can give measurements of FRC and the degree of nonuniformity of gas distribution in the lungs, but the multiple-breath test more accurately measures absolute lung volumes.

## Forced Oscillations Technique (FOT)

**ATS/ERS 2007: An Official American Thoracic Society/European Respiratory Society Statement: Pulmonary Function Testing in Preschool Children**

***Nicole Beydon , et al - Am J Respir Crit Care Med Vol 175. pp 1304–1345, 2007.***

The FOT is a simple, noninvasive technique performed during tidal breathing that is relatively easy to apply in preschool children. An external pressure wave is applied, usually at the mouth, and the resulting pressure–flow relationship is analyzed in terms of respiratory impedance. The latter expresses the impediment to flow in the respiratory system that includes both frictional losses and elastic and inertial loads. The FOT has been successfully performed in settings ranging from the field study to the emergency room. A number of studies have demonstrated that the FOT was able to identify airway obstruction and responses to bronchodilators and bronchoconstrictors.

**ERS 2003: The FOT in clinical practice. Methodology, recommendations and future developments**

***Oostveen E, MacLeod D, Lorino H, Farré R, Hantos Z, Desager K, Marchal F - Eur Respir J 2003; 22: 1026–1041***

The forced oscillation technique (FOT) is a noninvasive method with which to measure respiratory mechanics. FOT employs small-amplitude pressure oscillations superimposed on the normal breathing and therefore has the advantage over conventional lung function techniques that it does not require the performance of respiratory manoeuvres. FOT data, especially those measured at the lower frequencies, are sensitive to airway obstruction, but do not discriminate between obstructive and restrictive lung disorders. Forced oscillation technique is a reliable method in the assessment of bronchial hyperresponsiveness in adults and children. Moreover, in contrast with spirometry where a deep inspiration is needed, forced oscillation technique does not modify the airway smooth muscle tone. Forced oscillation technique has been shown to be as sensitive as spirometry in detecting impairments of lung function due to smoking or exposure to occupational hazards. Together with the minimal requirement for the subject's cooperation, this makes forced oscillation technique an ideal lung function test for epidemiological and field studies. Novel applications of forced oscillation technique in the clinical setting include the monitoring of respiratory mechanics during mechanical ventilation and sleep.

## Respiratory Mechanics

**ATS/ERS 2002 : Statement on Respiratory Muscle Testing**

***Am J Respir Crit Care Med Vol 166. Pp 518-624, 2002***

The principal advantage of volitional tests is that they give an estimate of inspiratory or expiratory muscle strength, are simple to perform, and are well tolerated by patients. However, it can be difficult to ensure that the subject is making a truly maximal effort. Measurement of the maximum static inspiratory pressure that a subject can generate at the mouth (PI max) or the maximum static expiratory pressure (PE max) is a simple way to gauge inspiratory and expiratory muscle strength. The pressure measured during these maneuvers reflects the pressure developed by the respiratory muscles (Pmus),

## Cardio Pulmonary Exercise Test (CPET)

**Use of exercise testing in the evaluation of interventional efficacy: an official ERS statement.**

***Puente-Maestu L, Palange P, Casaburi R, Laveneziana P, Maltais F, Neder JA, O'Donnell DE, Onorati P, Porszasz J, Rabinovich R, Rossiter HB, Singh S, Troosters T, Ward S. Eur Respir J. 2016 Feb;47(2):429-60***

"In respiratory patients, exercise testing is useful in the clinical and research setting to assess the effects of interventions. It also allows appraisal of the degree and mechanisms of impairment, and it is a strong independent prognostic factor. Several methods for evaluating exercise capacity are available. The severity and cause of exercise intolerance are best assessed by conducting standardised laboratory exercise testing in which detailed physiological measurements are made while patients perform cycle ergometry or treadmill walking. Protocols can be either constant ("endurance") or incremental. Simpler tests are also used, although the physiological information gathered is more limited: the 6MWT is relatively simple and has been used extensively; the ISWT and ESWT are better standardised and have been also used in several clinical trials."

**ERS Task Force 2007: Recommendations on the use of exercise testing in clinical practice**

***Palange P, Ward SA, Carlsen KH, Casaburi R, Gallagher CG, Gosselink R, O'Donnell DE, Puente-Maestu L, Schols AM, Singh S, Whipp BJ - Eur Respir J 2007; 29: 185–209***

The purpose of this document is to present recommendations on the clinical use of exercise testing in patients with cardiopulmonary disease, with particular emphasis on the evidence base for the functional evaluation, prognosis and assessment of interventions..Cardiopulmonary exercise testing (CPET) should be considered the gold standard for evaluating the causes of exercise intolerance in patients with pulmonary and cardiac disease, and is based on the principle that system failure typically occurs while the system (e.g. muscle–energetic, cardiovascular or pulmonary) is under stress.

**2003 ATS/ACCP Statement on Cardiopulmonary Exercise Testing**
**American Thoracic Society (ATS) and the American College of Chest Physicians (ACCP) American J. Respiratory Critical Care Medicine, Vol. 167, 211; 277, 2003**

The purpose of this Joint American Thoracic Society/American College of Chest Physicians (ATS/ACCP) statement is to provide a comprehensive, conceptually balanced document on CPET, which formulates guidelines and recommendations to facilitate interpretation and clinical application on the basis of the current best scientific knowledge and technical advances. The focus of this document is on clinical indications, standardization issues, and interpretative strategies for CPET in adults. The scope of issues includes (1) indications for CPET; (2) methodology—equipment, modality, protocols, conduct of the test, monitoring, safety, and personnel issues; (3) measurements and graphic interrelationships, the physiologic response to exercise in "normal" subjects, and the consequences of pathophysiologic derangements on exercise performance; (4) normal reference values; (5) interpretation, including case study analysis; and (6) future recommendations for research.

**ERS 1997: Clinical exercise testing with reference to lung diseases: indications, standardization and interpretation strategies**
**J. Roca and B.J. Whipp, A.G.N. Agustí, S.D. Anderson, R. Casaburi, J.E. Cotes, C.F. Donner, M. Estenne, H. Folgering, T.W. Higenbottam, K.J. Killian, P. Palange, A. Patessio, C. Prefaut, R. Sergysels, P.D. Wagner and I. Weisman - European Respiratory Journal 1997; 10: 2662-2689**

The present document is essentially focused on clinical problems commonly faced in the study of patients with pulmonary diseases. CPET is an area of growing interest in pulmonary medicine for three major reasons: 1) its large potential clinical applicability (see section on Indications); 2) the essentially noninvasive nature of the testing; and 3) provision of information that cannot be obtained through conventional lung function testing performed at rest.