

AARC Clinical Practice Guideline

Body Plethysmography: 2001 Revision & Update

BP 1.0 PROCEDURE:

Body plethysmography for determination of thoracic gas volume (VTG) and airways resistance (R_{aw}).

BP 2.0 DESCRIPTION/DEFINITION:

During body plethysmography, the subject is enclosed in a chamber equipped to measure pressure, flow, or volume changes. The most common measurements made using the body plethysmograph are VTG and R_{aw} .^{1,2} Airways conductance (G_{aw}) is also commonly calculated as the reciprocal of R_{aw} . Specific airways conductance (ie, conductance/unit of lung volume) is routinely reported as sG_{aw} . Other tests that can be administered in the body plethysmograph include spirometry, bronchial challenge, diffusing capacity (D_{LCO}), single-breath nitrogen (N_2), multiple-breath N_2 washout, pulmonary compliance, and occlusion pressure. These will not be discussed as part of this guideline. Some have been previously addressed.³⁻⁶

2.1 VTG is expressed in liters (BTPS, or body temperature and pressure saturated) and is the volume of gas in the lung when the mouth shutter is closed. In plethysmographic studies, it is commonly used to represent the functional residual capacity (FRC).

2.2 R_{aw} is reported in $\text{cm H}_2\text{O}/\text{L}/\text{s}$ (ie, $\text{cm H}_2\text{O} \cdot \text{L}^{-1} \cdot \text{s}^{-1}$).

2.3 sG_{aw} is reported in $\text{L}/\text{s}/\text{cm H}_2\text{O}$ (ie, $\text{L} \cdot \text{s}^{-1} \cdot \text{cm H}_2\text{O}^{-1}$) and is the reciprocal of the R_{aw} ($1/R_{aw}$) divided by the lung volume at which the resistance measurement is made.

BP 3.0 SETTINGS:

3.1 Pulmonary function laboratories

3.2 Cardiopulmonary laboratories

3.3 Clinics and physician's offices

BP 4.0 INDICATIONS:

Body plethysmographic determination of VTG, R_{aw} , and sG_{aw} may be indicated:

4.1 for diagnosis of restrictive lung disease;

4.2 for measurement of lung volumes to distinguish between restrictive and obstructive processes;

4.3 for evaluation of obstructive lung diseases, such as bullous emphysema and cystic fibrosis, which may produce artifactually low results if measured by helium dilution or N_2 washout.⁷ With simultaneously determined volumes, an index of trapped gas (ie, $\text{FRC}_{\text{plethysmograph}}/\text{FRC}_{\text{He dilution}}$) can be established.⁸

4.4 for measurement of lung volumes when multiple repeated trials are required or when the subject is unable to perform multibreath tests;⁹

4.5 for evaluation of resistance to airflow;¹⁰

4.6 for determination of the response to bronchodilators, as reflected by changes in R_{aw} , sG_{aw} , and VTG;¹¹

4.7 for determination of bronchial hyperreactivity in response to methacholine, histamine, or isocapnic hyperventilation as reflected by changes in VTG, R_{aw} , and sG_{aw} ;^{12,13}

4.8 for following the course of disease and response to treatment.

BP 5.0 CONTRAINDICATIONS:

Relative contraindications to body plethysmography are:

5.1 mental confusion, muscular incoordination, body casts, or other conditions that prevent the subject from entering the plethysmograph cabinet or adequately performing the required maneuvers (ie, panting against a closed shutter);

5.2 claustrophobia that may be aggravated by entering the plethysmograph cabinet;

5.3 presence of devices or other conditions, such as continuous intravenous infusions with pumps or other equipment that will not fit into the plethysmograph, that should not be discontinued, or that might interfere with pressure

changes (eg, chest tube, transtracheal O₂ catheter, or ruptured eardrum);

5.4 continuous oxygen therapy that should not be temporarily discontinued.

BP 6.0 HAZARDS/COMPLICATIONS:

6.1 VTG and R_{aw} measurements require the subject to pant against a closed shutter; improper panting technique may result in excessive intrathoracic pressures.

6.2 Prolonged confinement in the plethysmograph chamber could result in hypercapnia or hypoxia; however, because of the limited length of the test and the fact that the plethysmograph must be vented periodically, this is an uncommon occurrence.

6.3 Transmission of infection is possible via improperly cleaned equipment (ie, mouthpieces) or as a consequence of the inadvertent spread of droplet nuclei or body fluids (patient-to-patient or patient-to-technologist).

BP 7.0 LIMITATIONS OF METHODOLOGY/ VALIDATION OF RESULTS:

Limitations of the body plethysmograph in measurement of VTG, R_{aw}, and sG_{aw} include but are not limited to:

7.1 overestimation of VTG in subjects with severe obstruction or induced bronchospasm unless a slow 'panting' speed (ie, approximately 1 cycle/s) is maintained.¹⁴⁻¹⁷

7.2 Erroneous measurement of VTG, R_{aw}, or sG_{aw} due to improper panting technique. Excessive pressure fluctuations or signal drift during panting may invalidate VTG, R_{aw}, or sG_{aw}.¹⁸

7.3 Nonpanting measurements have been suggested for use in children or others who have difficulty mastering the panting maneuver.^{19,20} Nonpanting maneuvers in plethysmographs with built-in thermal leaks may invalidate VTG or R_{aw} measurements.^{2,21}

7.4 Computer-determined slopes of either VTG or R_{aw} tangents may be inaccurate. Many systems calculate the slopes using a best-fit regression analysis. This technique may produce widely varying results if extraneous data points are included (due to improper panting or excessive signal drift). All slopes should be visually inspected and adjusted according to an estab-

lished laboratory procedure.^{22,23}

7.5 Excessive abdominal gas or panting techniques that employ accessory muscles may increase the measured VTG, due to compression effects.²⁴

7.6 Plethysmography is a complex test. Careful calibration of multiple transducers is required. Attention to frequency response, thermal stability, and leaks is necessary.²⁵

7.7 Choice and application of reference values affect interpretation. Reference values for VTG using plethysmographically determined lung volumes are not widely available.

7.7.1 Make a tentative selection from whatever published reference values are available. The characteristics of the healthy reference population should match the study group with respect to age, body size, gender, and race. The equipment, techniques, and measurement conditions should be similar.

7.7.2 Following selection of seemingly appropriate reference values, compare measurements obtained from a representative sample of healthy individuals (10-20 subjects, over an appropriate age range) to the predicted values obtained from the selected reference values. If an appreciable number of the sample fall outside of the normal range, more appropriate reference values should be sought. This procedure detects only relatively gross differences between sample and reference populations.²⁶

BP 8.0 ASSESSMENT OF NEED:

8.1 See Section 4.0 Indications.

8.2 Protocols may define the need for measurement of lung volumes and airway resistance measurements based on the results of previously performed tests (ie, spirometry, diffusing capacity) and the clinical question to be answered.

BP 9.0 ASSESSMENT OF QUALITY & VALIDATION OF RESULTS:

The consensus of the Committee is that all diagnostic procedures should follow the quality model described in the NCCLS GP26-A A Quality System Model for Health Care.²⁷ (Fig. 1) The document de-

scribes a laboratory path of workflow model that incorporates all the steps of the procedure. This process begins with patient assessment and the generation of a clinical indication for testing through the application of the test results to patient care. The quality system essentials defined for all health care services provide the framework for managing the path of workflow. A continuation of this model for respiratory care services is further described in NCCLS HS4-A A Quality System Model for Respiratory Care.²⁸ In both quality models the patient is the central focus.

9.1.3 Documentation of results, therapeutic intervention (or lack of) and/or clinical decisions based on the testing should be placed in the patient's medical record.

9.1.4 The type of medications, dose, and time taken prior to testing and the results of the pretest assessment should be documented.

9.1.5 Report of test results should contain a statement by the technician performing the test regarding test quality (including patient understanding of directions and ef-

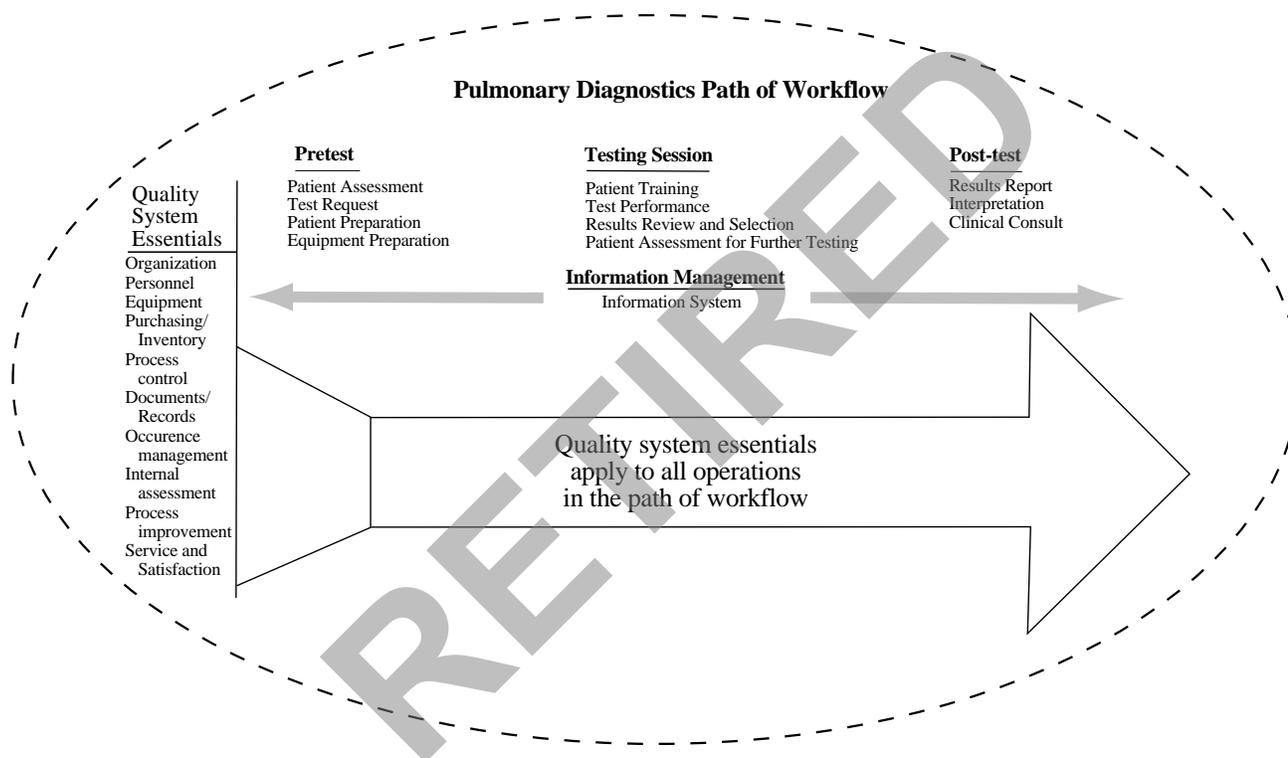


Fig. 1. Structure for a Quality System Model for a Pulmonary Diagnostics Service (From Reference 27, with permission)

9.1 General consideration include:

9.1.1 As part of any quality assurance program, indicators must be developed to monitor areas addressed in the path of workflow.

9.1.2 Each laboratory should standardize procedures and demonstrate intertechnologist reliability. Test results can be considered valid only if they are derived according to and conform to established laboratory quality control, quality assurance, and monitoring protocols.

fort expended) and, if appropriate, which recommendations were not met.²⁹⁻³¹

9.1.6 Test results should be interpreted by a physician, taking into consideration the clinical question to be answered.

9.1.7 Personnel who do not meet annual competency requirements or whose competency is deemed unacceptable as documented in an occurrence report should not be allowed to participate, until they have received remedial instruction and have

been re-evaluated.

9.1.8 There must be evidence of active review of quality control, proficiency testing, and physician alert, or 'panic' values, on a level commensurate with the number of tests performed.

9.2 Calibration and quality control measures specific to equipment used in plethysmography include:

9.2.1 Calibration at recommended frequencies, at any time accuracy is suspect, and when the equipment is moved to a different location.

9.2.2 On a daily basis, calibrate volume, mouth and box pressure.

9.2.3 At least monthly, manually calibrate systems in addition to daily use of the autocalibration system.

9.2.4 At least weekly, assess linearity of flow-sensing device.

9.2.5 At least quarterly, perform airway resistance with a known resistor and calculate results.³²

9.2.6 At least annually or at a frequency established by the laboratory on the basis of the tendency of the device to vary, check volume with isothermal bottle.³³

9.2.7 At least monthly and at any time accuracy is suspect, perform tests on standard subjects (biologic controls, or bio-QC).^{29,32}

9.2.8 Test standard subjects more frequently initially to establish statistical variation for comparison.

9.2.9 It may be advantageous to perform Bio-QC at weekly or semi-monthly intervals.

9.3 Test Quality Assessment: Results are valid if the equipment functions correctly and the subject is able to perform acceptable and reproducible maneuvers.

9.3.1 VTG maneuvers are acceptable when:

9.3.1.1 the displayed or recorded tracing indicates proper panting technique (the loop generated against a closed shutter should be closed or nearly so). The patient should support his/her cheeks with the hands to prevent pressure changes induced by the mouth.³⁴

This should be done without supporting the elbows or elevating the shoulders.

9.3.1.2 Recorded pressure changes should be within the calibrated pressure range of each transducer (See Section 10.1.3). The entire tracing should be visible. Pressure changes that are too large or too small may yield erroneous results.

9.3.1.3 Thermal equilibrium should be evident; tracings should not drift on the display or recording. (This typically takes 1-2 minutes.)

9.3.1.4 The panting frequency is approximately 1 Hz. Nonpanting maneuvers may be acceptable if the plethysmograph system is specifically designed to perform such maneuvers.^{14,35}

9.4. R_{aw} and sG_{aw} maneuvers may be considered acceptable if:

9.4.1 they meet criteria given in Sections 9.3.1.1 through 9.3.1.3;

9.4.2 the open-shutter panting maneuver shows a relatively closed loop, particularly in the range of +0.5 to -0.5 L/s;

9.4.3 the panting frequency during serial measurements in a given patient is kept constant to aid in interpretation. Consensus of the group suggests a range of 90-150 cycles per minute (1.5-2.5 Hz). Frequency should be held constant for within-testing session comparisons (ie, pre- and post-bronchodilator testing) and serial testing.

9.5 Test Results Reporting:

9.5.1 The reported VTG

9.5.1.1 should be averaged from a minimum of 3-5 separate, acceptable panting maneuvers;^{36,37}

9.5.1.2 should be calculated using values that agree within 5% of the mean (widely varying values should be averaged, and reported as variable);

9.5.1.3 should indicate whether the thoracic volume was at FRC or at some other level;

9.5.1.4 should be compared with other lung volume determinations (He dilution, N_2 washout) if such are being performed;

9.5.1.5 should be corrected for patient weight for some systems.

9.5.2 Lung Volumes including the slow vital capacity (VC) maneuver and its subdivisions inspiratory capacity (IC) and expiratory reserve volume (ERV) should be performed during the same testing session. The ERV, IC, and VC should be measured in conjunction with each VTG trial before disconnecting from the measuring system. Add tracing to illustrate correct performance.

9.5.2.1 The largest volume of VC or FVC obtained should be used for calculation of derived lung volumes (ie, total lung capacity, or TLC, residual volume, or RV, and RV/TLC%).

9.5.2.2 The mean values should be reported for IC and ERV from acceptable VTG maneuvers.

9.5.2.3 There are various methods to calculate TLC, but by consensus the Committee recommends use of: TLC = mean FRC + mean IC*

*(Note: Mean IC should be close to the largest IC)

RV = TLC – largest VC

9.6 The reported R_{aw} and sG_{aw}

9.6.1 should be calculated from the ratio of closed and open shutter tangents for each maneuver.³⁸ (Airway resistance and lung volume are interdependent in a non-linear fashion);

9.6.2 should be averaged from 3-5 separate, acceptable maneuvers as calculated in 9.4; reproducibility should be based on sG_{aw} and the suggested limit for variance is within 10% of the mean; (eg, if the measured results are ≤ 0.17 , accept ± 0.01 or if the measured results are ≥ 0.20 , use ± 0.02)³⁹

9.6.3 should have the open-shutter tangent (V/P_{box}) measured between flows of +0.5 and -0.5 L/s. For loops that display hysteresis, the inspiratory limbs may be used;³⁸

9.6.4 should have the sG_{aw} calculated using the VTG at which the shutter was closed for each individual maneuver.²⁴

9.7 Report of test results should contain a statement by the technologist performing the test concerning test quality and, if appropriate, which recommendations were not met.

9.8 Reference equations: Each laboratory should select reference equations appropriate for the methods and the population tested. Guidance for defining and determining reference intervals is provided in American Thoracic Society (ATS)³² and NCCLS⁴⁰ documents.

9.9 Test quality monitoring: Plethysmography results should be subject to ongoing review by a supervisor, with feedback to the technologist. The monitoring should include visual inspection of the VTG and R_{aw} loops and fitted lines. Quality assurance (QA) and/or quality improvement (QI) programs should be designed to monitor the technologist both initially and on an ongoing basis.

BP 10.0 RESOURCES:

10.1 Equipment:

10.1.1 Volume-measuring devices used in the plethysmograph (ie, the pneumotachometer) should meet or exceed ATS recommendations. A 3-L syringe should be available for calibration.³¹

10.1.2 Either pressure (constant volume) or flow-type plethysmographs may be used.

10.1.3 Transducers in the plethysmograph should meet prescribed range specifications:²⁴

Mouth pressure: ± 20 to 50 cm H₂O

Box pressure: ± 2 cm H₂O (500-L box)

Flow: 0.2 to 1.5 L/s

10.1.4 Pressure and volumes signals should be phase aligned up to 10 Hz.

10.1.5 A plenum or similar device that facilitates thermal equilibrium is recommended. Some plethysmographs utilize air conditioning to maintain thermal equilibrium.

10.1.6 The plethysmograph cabinet should be easy for the subject to enter and exit. The door should preferably be operable from within the box. The cabinet should be equipped with an intercom and should provide adequate visibility for both the technologist and the subject.

10.1.7 The plethysmograph system, if computerized, should allow for technologist adjustment of open- and closed-shutter tangents.

10.1.8 Calibration devices should include (in addition to a 3-L syringe) 30-50 mL

sine-wave pump (variable speed, used primarily for calibration of pressure boxes), water manometer ± 20 cm H₂O (used for calibration of the mouth pressure transducer), and rotameter 0 to 1.5 L/s (used for calibration of the pneumotachometer).

10.2 Personnel: Plethysmography should be performed under the direction of a physician trained in pulmonary function testing. It may be performed by technologists who meet criteria for either Level I or Level II. Plethysmographic results can be compromised if the test is performed by inadequately trained personnel.

10.2.1 Level I: The technologist performing plethysmography should be a high school graduate or equivalent with a demonstrated ability to perform spirometry and lung volume determinations. Level I personnel should perform plethysmography only under the supervision of a Level II technologist or a physician.

10.2.2 Level II: Personnel supervising plethysmography should have formal education and training.⁴¹ This may be part of an accredited program in respiratory therapy or pulmonary function technology or 2 years of college work in biological sciences and mathematics. Level II personnel should also have 2 or more years experience performing spirometry, lung volumes, and diffusing capacity tests. Attainment of the credential of Certified Pulmonary Function Technologist (CPFT) or Registered Pulmonary Function Technologist (RPFT) is recommended.

BP 11.0 PATIENT MONITORING:

(See also Section 9.0 Assessment of Quality)

11.1 Evaluate the patient's breathing pattern to verify a stable FRC level.

11.2 Verify appropriate shutter-closure timing.

11.3 Gauge the level of understanding (of test instructions), effort, and cooperation by the subject.

BP 12.0 FREQUENCY:

The frequency with which plethysmography is repeated should depend on the clinical question(s) to be answered.

BP 13.0 INFECTION CONTROL:

13.1 The staff, supervisors, and physician-directors associated with the pulmonary laboratory should be conversant with "Guideline for Isolation Precautions in Hospitals"⁴² and develop and implement policies and procedures for the laboratory that comply with its recommendations for Standard Precautions and Transmission-Based Precautions.

13.2 The laboratory's manager and its medical director should maintain communication and cooperation with the institution's infection control service and the personnel health service to help assure consistency and thoroughness in complying with the institution's policies related to immunizations, post-exposure prophylaxis, and job- and community-related illnesses and exposures.⁴³

13.3 Primary considerations include adequate handwashing,⁴⁴ provision of prescribed ventilation with adequate air exchanges,⁴⁵ careful handling and thorough cleaning and processing of equipment,⁴⁶ and the exercise of particular care in scheduling and interfacing with the patient in whom a diagnosis has not been established.⁴⁵ Considerations specific for plethysmography measurement include:

13.3.1 The use of filters is neither recommended nor discouraged. Filters may be appropriate for use in systems that use valves or manifolds on which deposition of expired aerosol nuclei is likely.⁴⁷

13.3.2 If filters are used in gas-dilution procedures, their volume should be subtracted when FRC is calculated.

13.3.3 If filters are used in the plethysmograph system, the resistance of the filters should be subtracted from the airways resistance calculation.

13.3.4 Nondisposable mouthpieces and equipment parts that come into contact with mucous membranes, saliva, and expirate should be cleaned and sterilized or subjected to high-level disinfection between patients.⁴⁶ Gloves should be worn when handling potentially contaminated equipment.

13.3.5 Flow sensors, valves, and tubing not in direct contact with the patient should be routinely disinfected according to the hospital's infection control policy. Any equipment surface that displays visible condensation from expired gas should be disinfected or sterilized before it is reused.

13.3.6 Water-sealed spirometers should be drained weekly and allowed to dry.³⁰

13.3.7 Closed circuit spirometers, such as those used for He-dilution FRC determinations, should be flushed at least 5 times over their entire volume to facilitate clearance of droplet nuclei. Open circuit systems need only have the portion of the circuit through which rebreathing occurs decontaminated between patients.

14.0 AGE-SPECIFIC ISSUES:

Test instructions should be provided and techniques described in a manner that takes into consideration the learning ability and communications skills of the patient being served.

14.1 Neonatal: This Guideline does not apply to the neonatal population.

14.2 Pediatric: These procedures are appropriate for children who can perform spirometry of acceptable quality and can adequately follow directions for plethysmographic testing.

14.3 Geriatric: These procedures are appropriate for members of the geriatric population who can perform spirometry of acceptable quality and adequately follow directions for plethysmographic testing.

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The current Pulmonary Function Clinical Practice Guidelines Committee updated an earlier version (Body plethysmography. *Respir Care* 1994;39(12):1184-1190) and wishes to acknowledge those individuals who provided input to that earlier version: Robert Brown, Michael Decker, and Kevin Shrake.

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ADDITIONAL READING

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