AARC Clinical Practice Guideline

Static Lung Volumes: 2001 Revision & Update

SLV 1.0 PROCEDURE:
Measurement of static lung volumes and capacities in adults and in children (age ≥ 5). This guideline focuses on commonly used techniques for measuring lung volumes, including spirometry, gas-dilution determination of functional residual capacity (FRC), and whole-body plethysmography determination of thoracic gas volume (VTG). Other methods (eg, single-breath nitrogen, single-breath helium, and roentgenologic determinations of lung volumes) are not discussed in this document, but may be useful in certain situations.

SLV 2.0 DESCRIPTION/DEFINITIONS:

2.1 Static lung volumes are determined using methods in which airflow velocity does not play a role. The sum of two or more lung-volume subdivisions constitutes a lung capacity. The subdivisions and capacities are expressed in liters at body temperature and pressure saturated with water vapor (BTPS).

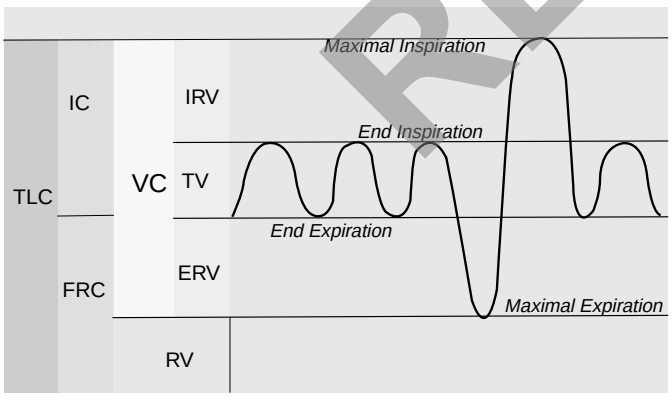

Fig. 1. Subdivisions of Lung Volume

2.2 Tidal volume is the volume of air that is inhaled or exhaled with each respiratory cycle.[1] (Although both V_T and TV have been used to denote this volume, TV is used in this guideline.) It varies with the conditions under which it is measured (eg, rest, exercise, posture). When TV is reported, an average of at least 6 breaths should be used.[2] (Fig. 1)

2.3 Inspiratory reserve volume (IRV) is the maximal volume of air that can be inhaled from TV end-inspiratory level.[2]

2.4 Expiratory reserve volume (ERV) is the maximal volume of air that can be exhaled after a normal tidal exhalation (ie, from functional residual capacity, or FRC).[2]

2.5 Residual volume (RV) is the volume of gas remaining in the lung at the end of a maximal expiration.[1] It may be calculated by subtracting ERV from FRC (RV = FRC – ERV) or by subtracting vital capacity (VC) from total lung capacity, or TLC (RV = TLC – VC).

2.6 Inspiratory capacity (IC) is the maximal volume of air that can be inhaled from the tidal-volume end-expiratory level (ie, FRC). It is equal to the sum of TV and IRV.[2]

2.7 Vital capacity (VC) is the volume change that occurs between maximal inspiration and maximal expiration. The subdivisions of the VC include TV, inspiratory reserve volume (IRV), and expiratory reserve volume (ERV). The largest of three technically satisfactory VC maneuvers should be reported. The two largest VCs should agree within 5% or 100 mL, whichever is larger. The volume change can be accomplished in several ways.[2]

2.7.1 Two-stage VC: a slow maximal inspiration from TV end-expiratory level after a normal exhaled TV, followed by quiet breathing, followed by a slow maximal expiration from TV (ie, end-expiratory level, or functional residual capacity (ie, FRC). The reverse maneuver is also acceptable;

2.7.2 Forced vital capacity (FVC): the volume of air exhaled during a forced maximal expiration following a forced maximal inspiration. The FIVC is the forced VC obtained during a maximal inspiration following a maximal expiration.

2.8 FRC is the volume of air in the lung at the average TV end-expiratory level. It is the sum of the ERV and RV. When subdivisions of lung volume are reported, the method of measurement should be specified (eg, helium dilution, nitrogen washout, body plethysmography).[2]

2.9 Thoracic gas volume (VTG) is the volume of air in the thorax at any point in time and at any level of thoracic expansion. It is usually measured by whole-body plethysmography. It may be determined at any level of lung inflation; however, it is most commonly determined at or near FRC.[2] As an alternative, lung volume may be tracked continuously, and FRC determined from VTG by addition or subtraction of volume.

2.10 Total lung capacity (TLC) is the volume of air in the lung at the end of a maximal inspiration. It is usually calculated in one of two ways: (1) TLC = RV + VC or (2) TLC = FRC + IC. The method of measurement (eg, gas dilution, body plethysmography) should be specified.[2]

SLV 3.0 SETTINGS:

3.1 Pulmonary function laboratories

3.2 Cardiopulmonary laboratories

3.3 Clinics and physicians' offices

3.4 Patient care areas

3.5 Study and field settings

SLV 4.0 INDICATIONS:

Indications include but are not limited to the need

4.1 to diagnose restrictive disease patterns;[3]

4.2 to differentiate between obstructive and restrictive disease patterns,[2] particularly in the presence of a reduced VC;[4]

4.3 to assess response to therapeutic interventions (eg, drugs, transplantation, radiation, chemotherapy, lobectomy, lung-volume-reduction surgery);

4. 4 to aid in the interpretation of other lung function tests (eg, DL/VA, sG_{aw}, RV/TLC;[2]

4. 5 to make preoperative assessments[2] in patients with compromised lung function (known or suspected) when the surgical procedure is known to affect lung function;

4. 6 to provide an index of gas trapping (by comparison of gas dilution techniques with plethysmographic measurements).[5]

SLV 5.0 CONTRAINDICATIONS:

5.1 No apparent absolute contraindications exist; the relative contraindications for spirometry are appropriate and may include:[2,6,7]

5.1.1 hemoptysis of unknown origin;

5.1.2 untreated pneumothorax;

5.1.3 pneumothorax treated with a chest tube—because the chest tube may introduce leaks and interfere with gas-dilution measurements;

5.1.4 unstable cardiovascular status;

5.1.5 thoracic and abdominal or cerebral aneurysms.

5.2 With respect to whole-body plethysmography, such factors as claustrophobia, upper body paralysis, obtrusive body casts, intravenous (I.V.) pumps, or other conditions that immobilize or prevent the patient from fitting into or gaining access to the 'body box' are a concern. In addition, the procedure may necessitate stopping I.V. therapy or supplemental oxygen.

SLV 6.0 HAZARDS/COMPLICATIONS:

6.1 Infection may be contracted from improperly cleaned tubing, mouthpieces, manifolds, valves, and pneumotachometers.

6.2 Hypoxemia may result from interruption of O_2 therapy in the body box.

6.3 Ventilatory drive may be depressed in susceptible subjects (ie, some CO_2 retainers) as a consequence of breathing 100% oxygen during the nitrogen washout.[8] Such patients should be carefully observed.

6.4 Hypercapnia and/or hypoxemia may occur during helium-dilution FRC determinations as a consequence of failure to adequately remove CO_2 or add O_2 to the rebreathed gas.

SLV 7.0 LIMITATIONS OF METHODOLOGY/ VALIDATION OF RESULTS:

7.1 Patient-related limitations:

7.1.1 Slow VC is effort-dependent and requires understanding and motivation on the subject's part. Physical and/or mental impairment may limit patient's ability to perform.

7.1.2 Some patients may be unable to perform the necessary panting maneuver required for plethysmographic determination of FRC.

7.1.3 Some subjects are unable to maintain mouth seal or cooperate adequately for the

time necessary to perform the test. Cough is a common cause of such limitations.

7.1.4 Certain pathologic conditions in the subject can cause a leak in a lung-volume-measurement system (eg, perforated eardrum, tracheostomy, transtracheal catheter, chest tube).

7.1.5 FRC measured by gas dilution may be underestimated in individuals with airflow limitation and air trapping.[9,10] Body plethysmography may overestimate FRC in subjects with severe airway obstruction or induced bronchospasm at panting frequencies greater than 1 Hz (1 cycle/second).[11-13]

7.1.6 Elimination of nitrogen from tissues and blood can result in overestimation of the FRC in healthy subjects unless appropriate corrections are made.[2]

7.2 Test validation encompasses those calibration and procedural elements that help assure credible results:

7.2.1 Spirometry

7.2.1.1 Spirometers (volume-displacement devices or flow-sensing devices) should meet the American (1994) and European Thoracic Societies' (1993) current accepted standards.[2,3] Volume-displacement spirometers should be leak tested when calibrated (eg, daily).[14]

7.2.1.2 The VC should be measured as close as possible in time to the FRC determination.[2]

7.2.2 Gas-dilution methods for FRC determination:

7.2.2.1 Open-circuit multibreath nitrogen washout method

7.2.2.1.1 Test should be continued for 7 minutes or until N_2 concentration falls below 1.0%.[15] In subjects with airflow obstruction and air trapping, the time period for measuring FRC may need to be extended.

7.2.2.1.2 A minimum of 15 minutes should elapse before test is repeated.[16]

7.2.2.1.3 Initial alveolar nitrogen concentration of 80% can be assumed[2] if patient has been breathing room air for at least 15 minutes.

7.2.2.2 Closed-circuit multibreath helium equilibration method

7.2.2.2.1 The helium concentration should be measured at least every 15 seconds, and water vapor should be removed from the fraction of gas that is introduced into the helium analyzer.[2] The reference cell of the He katharometer should also have a water absorber in-line, if room air is used for zeroing.

7.2.2.2.2 A mixing fan should circulate and completely mix the air throughout the main circuit.

7.2.2.2.3 The breathing valve and mouthpiece (without a filter) should add < 60 mL dead space to the system for adults and a proportionately reduced increase for pediatric subjects and should be easy to disassemble for cleaning.

7.2.2.2.4 Gas mixing is considered complete when the change in helium concentration has been constant over a 2-minute period (ie, changes less than 0.02%) or 10 minutes has elapsed.[4] If the helium concentration can be read directly or processed by computer, helium equilibration can be assumed when the change is < 0.02% in 30 seconds.[2]

7.2.2.2.5 The need to correct for body absorption of helium is controversial.

7.2.2.2.6 The delay between the repeated measurements should be at least the same as the time taken to reach equilibrium or 5 minutes, whichever is greater.[17,18]

7.2.4 Whole body plethysmography

7.2.4.1 The frequency of panting breathing movements against the shutter should be 1 cycle/second.[11-13,19]

7.2.4.2 The cheeks and chin should be firmly supported with both hands. This should be done without supporting the elbows or elevating the shoulders.[20]

7.2.4.3 Plethysmographic determination of FRC is the method of choice in patients with airflow limitation and air trapping.[2]

7.2.4.4 This method may be the more practical method in subjects with short attention spans or inability to stay on the mouthpiece (eg, children).

7.3 Reproducibility of results is essential to validation and test quality.

7.3.1 Multiple FRC determinations by gas dilution should be made, with at least two trials agreeing within 10% of the mean.[21]

7.3.2 FRC determinations by body plethysmography (at least 3 separate trials) should agree within 5% of the mean.[22]

7.3.3 IC and ERV measurements should agree within 5% or 60 mL (of the mean) whichever is larger. In patients who have large variability, this should be noted.

7.3.4 The two largest VC measurements should agree within 200 mL.[3]

7.4 Clear and complete reporting of results is essential to test quality.

7.4.1 The average FRC value should always be reported (and should ideally include the variability).

7.4.2 The largest volume of either VC or FVC should be reported

7.4.3 The largest reproducible value should be reported for IC and ERV, as described in 7.3.3.

7.4.4 Various methods are used for calculating TLC and RV.[23] The consensus of the Committee is that the two acceptable methods for reporting TLC and RV from FRC determinations made using gas dilution techniques are:

TLC = mean FRC + largest IC,
RV = TLC – largest VC; or
RV = mean FRC – largest ERV,
TLC = RV + largest VC.

For body plethysmographic determinations, a VC maneuver (with its IC and ERV subdivisions) should be performed in conjunction with each VTG maneuver and the TLC calculated as

TLC = FRC + IC.*

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

The reported TLC should be the mean of all acceptable maneuvers; the RV should be calculated as:

RV = mean TLC – largest VC.

7.5 Conditions under which testing is done can affect results and should be controlled to the extent possible. If certain conditions cannot be met, the written report should reflect that.

7.5.1 Lung volumes are influenced by body position[24,25] and should be made in the sitting position. If another position is used, it should be noted.[2]

7.5.2 Breathing movements should not be restricted by clothing.

7.5.3 Diurnal variations in lung function may cause differences and, thus, if serial measurements are to be performed, the time of the day that measurements are made should be held constant.[2]

7.5.4 The patient should not have smoked for at least 1 hour prior to the measurements.

7.5.5 The patient should not have had a large meal shortly before testing.

7.5.6 Nose clips should always be worn during testing.[2]

7.5.7 Measurements made at ambient temperature and pressure saturated with water vapor (ATPS) conditions are corrected to body temperature and pressure saturated with water vapor (BTPS) conditions.

7.5.8 No corrections are necessary for altitude because no consistent differences in lung volumes (TLC, VC, FRC, and RV) due solely to altitude have been found from sea level up to 1,800 meters.[26-28]

7.5.9 After the mouthpiece is in place, the patient should be asked to breathe quietly in order to become accustomed to the apparatus and attain a stable breathing pattern. The end-expiratory level should be reproducible within 100 mL.

7.5.10 VC can be measured before disconnecting the patient from measuring systems. As an alternative, the patient can be disconnected and the VC performed immediately afterward.

7.5.11 If expired VC is measured with a CO_2 absorber in the system, an appropriate volume correction must be made. (1.05 × expired volume is the correction commonly incorporated into commercial software.)

7.5.12 If a filter is used during FRC measurement, the filter volume must be subtracted.

7.6 Choice of reference values may affect interpretation.

7.6.1 Make a tentative selection from published reference values. 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.

7.6.2 Following selection of apparently 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 falls outside of the normal range, more appropriate reference values should be sought. This procedure detects only relatively gross differences between sample and reference population.[29]

7.6.3 Predicted values for RV, FRC, and TLC should be derived from the same reference population.

7.7 Expression of results

7.7.1 The upper and lower limits of normal may be derived from the standard error of the estimates (SEE) around the regression lines. The two-tail 95% confidence interval can be estimated by multiplying $\pm 1.96 \times$ SEE. A one-tailed 95% confidence interval can also be used for parameters in which only an abnormal high or low limit of normal is needed; the one-tailed limit is estimated by multiplying $\pm 1.64 \times$ SEE and subtracting this value from the mean.[22,24] These methods of estimating the limits of normal are applicable only if the reference data are normally distributed (Gaussian).[4]

7.7.2 The common practice of expressing results as percent predicted and regarding 80% predicted as the lower limit of normal is not valid unless the standard deviation (SD) of the reference data is proportional to the mean value.[30]

SLV 8.0 ASSESSMENT OF NEED (See SLV 4.0 Indications.)

Technologist-driven protocols (TDP) may be useful for assessing the need for lung-volume determination, particularly in the context of other pulmonary function results (eg, spirometry, diffusing capacity).

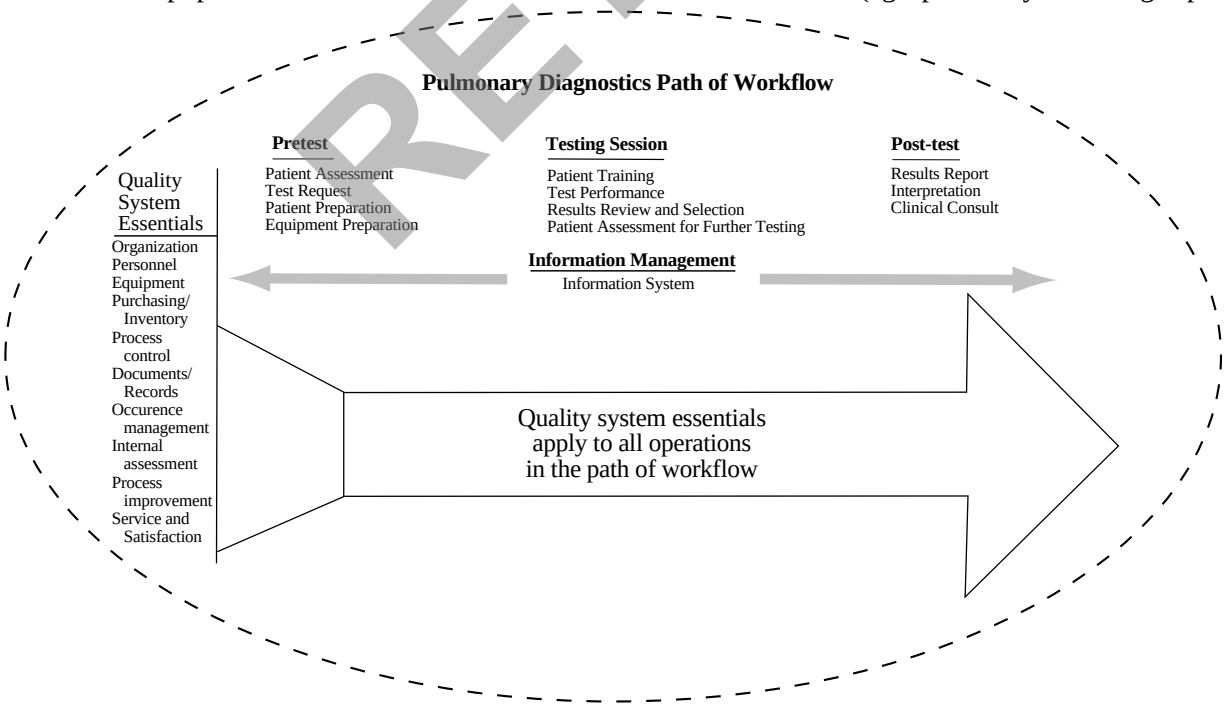

Fig. 2. Structure for a Quality System Model for a Pulmonary Diagnostics Service (From Reference 31, with permission)

SLV 9.0 ASSESSMENT OF QUALITY OF TEST AND VALIDITY 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.[31] (Fig. 2) The document describes 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.[32] In both quality models the patient is the central focus.

9.1 General considerations 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.

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 effort expended) and, if appropriate, which recommendations were not met.[2,3,33]

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 measures specific to equipment used in measuring lung volumes include:

9.2.1 Spirometers and/or other volume transducers should be calibrated daily using a 3-L syringe or another more sophisticated device.[3] Volume-based spirometers should be checked for leaks.

9.2.2 Gas dilution systems should have their gas analyzers, (ie, He, N_2, O_2, CO_2) calibrated according to the manufacturer's recommendations immediately before each test. Some analyzers may require more frequent calibration.

9.2.3 Gas conditioning devices such as CO_2 and water absorbers should be inspected daily.

9.2.4 Body plethysmographs (including each transducer) should be calibrated at least daily, according to the manufacturer's recommendations. Leak checks or calculation of time constants should be performed in accordance with the manufacturer's recommendations.

9.3 Quality control measures specific to measuring lung volumes include:

9.3.1 Lung volume analogs provide a means of checking the absolute accuracy and assessing precision. A 3-L syringe with/without an additional volume container can be used to check gas dilution systems (both open and closed circuit systems). As an alternative, a large-volume syringe can be used to assess the linearity of the associated gas analyzers, using a serial dilution technique.[34]

9.3.2 Isothermal bottles can be constructed

or purchased in order to check body plethysmograph function (volume accuracy).

9.3.3 Biologic controls should be used to assess the performance of the entire lung-volume system (transducers, gas analyzers, software). The means and standard deviations of 8-10 measurements of 2 or more healthy subjects may be used to check the precision of the system, as well as to troubleshoot when problems are suspected.

SLV 10.0 RESOURCES:

10.1 Equipment: Specifications should conform to recognized standards.

10.1.1 All spirometers (volumetric or flow-based) should meet or exceed the minimum recommendations of the American Thoracic Society.[3]

10.1.2 Helium analyzers (katharometers) should be linear from 0 to 10% with a resolution less than 0.05% He and an accuracy of 0.1%. The gas flow through the meter should be constant at 20 mL/min or more. The 95% response time of the system (analyzer, spirometer with fan) for a 2% step change should be ≤ 15 seconds.[2]

10.1.3 Plethysmographs should include:[2]

10.1.3.1 a patient compartment appropriate for the population to be tested;

10.1.3.2 a piston pump for box calibration and a manometer or similar device for mouth pressure calibration. A 3-liter syringe should be available for pneumotachometer calibration;

10.1.3.3 a vent to atmosphere (constant volume configurations);

10.1.3.4 a mouth shutter capable of closing within 0.1 seconds;

10.1.3.5 and an intercom for patient-technologist communication.

10.1.4 Nitrogen analyzers should have a range of 0-100% ± 0.5% with 50-millisecond response time or rapidly responding O_2 and CO_2 analyzers that allow calculation of the fraction of expired N_2 (FeN_2) should be incorporated.

10.2 Personnel

10.2.1 Lung-volume testing should be performed under the direction of a physician trained in pulmonary diagnostics.[35]

10.2.2 Personnel should be trained (with verifiable training and demonstrated competency) in all aspects of lung-volume determination, including equipment theory of operation, quality control, and test outcomes relative to diagnosis and/or medical history.[35]

10.2.3 Attainment of either the CPFT or RPFT credential is recommended by the Committee.

SLV 11.0 MONITORING:

The following should be monitored during lung-volume determinations:

11.1 reproducibility of repeated efforts;

11.2 presence or absence of adverse effects of testing on the patient during testing. (Patients on supplemental oxygen may require periods of time to rest on oxygen between trials.)

SLV 12.0 FREQUENCY:

The frequency of lung-volume measurements depends on the clinical status of the subject and the indications for performing the test.

SLV 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"[36] 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.[37]

13.3 Primary considerations include adequate handwashing,[38] provision of prescribed ventilation with adequate air exchanges,[39] careful handling and thorough cleaning and processing of equipment,[36] and the exercise of particular care

in scheduling and interfacing with the patient in whom a diagnosis has not been established. Considerations specific for lung-volume 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.[40]

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.[36,41] 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.[2]

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 system need only have the portion of the circuit through which rebreathing occurs decontaminated between patients.

SLV 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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