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LUNG VOLUME MEASUREMENTS: A REVIEW ARTICLE

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ABSTRACT

Through this article a brief explanation about basic volumes and capacities, average lung volumes in healthy adults, lung capacities in healthy adults has been provided. An overview of Lung volumes, its measurements and the basic instrumentation involved in it is been explained. The term “lung volume” usually refers to the volume of gas within the lungs, as measured by body plethysmography, gas dilution or washout. Gas volumes associated with the respiratory process are the main target of investigation; the principal instruments that have been used so far in the clinical routine and in research activity includes spirometer, Turbine meter, Impedance plethysmograph (strain gage plethysmograph) or of inductance (inductance plethysmograph) Total body plethysmograph.

KEYWORDS

Lung volume, Total lung capacity (TLC), The vital capacity (VC) and Spirometer.

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INTRODUCTION

The term “**lung volume**” usually refers to the volume of gas within the lungs, as measured by body plethysmography, gas dilution or washout. In contrast, lung volumes derived from conventional chest radiographs are usually based on the volumes within the outlines of the thoracic cage, and include the volume of tissue (normal and abnormal), as well as the lung gas volume. Lung volumes derived from computed tomography (CT) scans can include estimates of abnormal lung tissue volumes, in addition to normal lung tissue volumes and the volume of gas within the lungs¹⁻⁵.

BASIC VOLUMES AND CAPACITIES

The **functional residual capacity (FRC)** is the volume of gas present in the lung at end expiration during tidal breathing.

The **expiratory reserve volume (ERV)** is the volume of gas that can be maximally exhaled from the end-expiratory level during tidal breathing (i.e. from the FRC).

The maximum volume of gas that can be inspired from FRC is referred to as the **inspiratory capacity (IC)**.

The **inspiratory reserve volume (IRV)** is the maximum volume of gas that can be inhaled from the end-inspiratory level during tidal breathing.

Residual volume (RV) refers to the volume of gas remaining in the lung after maximal exhalation (regardless of the lung volume at which exhalation was started).

The volume of gas inhaled or exhaled during the respiratory cycle is called the **tidal volume (TV or VT)**.

The **thoracic gas volume (TGV or VTG)** is the absolute volume of gas in the thorax at any point in time and any level of alveolar pressure. Since this term is too nonspecific, it is recommended that its use should be discontinued and replaced with more specific terminology, for example, plethysmographic lung volume (abbreviated as VL, pleth), and FRC by body plethysmography or TGV at FRC (FRC, pleth).

Total lung capacity (TLC) refers to the volume of gas in the lungs after maximal inspiration, or the sum of all volume compartments.

The **vital capacity (VC)** is the volume change at the mouth between the positions of full inspiration and complete expiration. The following figure depicts above mentioned definitions⁶.

Lung volumes, capacities and its compartments

Lung volumes defined by reference to TLC, FRC and RV include:

Vital capacity (VC) = TLC – RV

Inspiratory capacity (IC) = TLC – FRC

Expiratory reserve volume (ERV) = FRC – RV

Inspiratory reserve volume (IRV) = TLC - (FRC + VT).

These four volumes (or "volume compartments") are ordinarily measured directly, e.g. spirometrically; i.e. they are not calculated from the terms on the right, though the forms of the equations might suggest this. The VC can be measured by full expiration from TLC or by full inspiration from RV (after expiration from FRC).

In obstructive diseases particularly these inspiratory (IVC) and expiratory (EVC) VC may differ. Because TLC is a relatively repeatable volume, insensitive to the prior "volume history" of the lungs, the different VC will be associated with different RV, if RV is taken to equal TLC-VC. ERV is best measured directly by full expiration from FRC.

Other terms, conventions and issues The terms "absolute lung volume" (VL) and "thoracic gas volume" (TGV) are synonymous and refer to the total volume of gas in the lungs under conditions of interest, which may or may not be named lung volume compartments such as RV, FRC or TLC. VL can be measured plethysmographically or by gas dilution or radiological techniques (with potential errors not addressed here) but it cannot be measured spirometrically, in contrast to lung volume changes or compartments such as VC and ERV which can. By convention, lung "capacities" consist of two or more "volumes". Thus, four lung volumes are used here to make up four capacities:

Function residual capacity (FRC) = RV + ERV

Inspiratory capacity (IC) = VT + IRV

Total lung capacity (TLC) = RV + ERV + VT + IRV

Vital capacity (VC) = ERV + VT + IRV.

This is a simple and useful convention, but it also presents conceptual traps often reflected in the literature. FRC is written, for example, as $FRC = RV + ERV$. This is true by definition, but the form of the equation suggests to some that RV and ERV are independent variables and FRC a dependent variable, so that, for example, if the FRC is abnormally high, the cause must be sought and understood in terms of high RV or ERV or both. But that is untrue; the answers lie in the mechanisms that determine FRC directly, as reviewed above.

As a second example, TLC is written as $TLC = RV + ERV + VT + IRV$. Again, this is true by definition, but again, abnormalities of this "capacity" are not to be explained by examining its four component volume compartments; biologically, it is not dependent on them. Instead, the answers lie in abnormalities of the muscle and elastic recoil forces that set static limits to maximum inspiration, i.e. that directly determine TLC as a biologically independent variable.

"Gas trapping" has several meanings, so the term should be defined when it is used. Gas may be "trapped" behind closed airways in the lung periphery, no longer in communication or exchanging normally with respired gas. Gas may also be "trapped" in the whole lung, or in lung regions, by dynamic mechanisms not involving airway closure, for example, when they empty slowly in relation to the time available for expiration. This can lead not only to abnormalities of gas exchange but also to dynamic increases in local or overall RV and FRC, and to such phenomena as "dynamic hyperinflation" or "auto positive end expiratory pressure (PEEP)"^{5, 9-13}. These two forms of "gas trapping" (i.e. with closed and with open airways) may coexist.

"Hyperinflation" also has several meanings, which should be made explicit when the term is used. In general it means that the volume of the lung, or of a lung region, is greater than normal, expected, or predicted, e.g. at RV, FRC or TLC. Thus, when the term "hyperinflation" is used,

the volume or region in question should be specified, e.g. hyperinflation at TLC, RV, left lower lobe. The mechanisms are many, including local and general airway obstruction, loss of lung recoil, increased ventilation, and both muscular and skeletal adaptations in the chest wall.

Clinical or physiological criteria may be used, or radiographic ones; actual volumes are often unknown and indeed the evidence for abnormality uncertain.

"Restriction" also has several meanings, which should be made clear when the term is used. The 1975 American College of Chest Physician (ACCP)-

American Thoracic Society (ATS) joint committee gave this definition: "Restrictive Pattern (restrictive ventilatory defect): Reduction of vital capacity not explainable by airways obstruction". Some find this definition unsatisfactory, and substitute the criterion that there must be a reduction in TLC before a "restrictive pattern" is said to exist. In this view, reduced VC unaccompanied by reduced maximal flows can suggest, but does not by itself demonstrate, "restriction", because TLC could still be normal or high, e.g. with bullous or cystic disease. Note that the term "restriction" as it is used in chest medicine implies nothing about mechanism, e.g. whether abnormalities exist in the lung (such as pulmonary fibrosis) or the chest wall (such as stiffness or muscle weakness) or even in the nervous system. In everyday use, however,

"Restriction" implies being held back, hindered, confined by external constraints; and so for clarity we think it desirable to specify neural or muscular abnormalities when they are responsible for low TLC and to reserve the term "restriction" for conditions in which the lungs and/or chest wall are abnormally stiff. Progressive reduction in TLC over months or years, even if all values lie within the predicted normal range, is accepted by some clinicians as evidence that a restrictive process, and perhaps a restrictive deficit, exists. For reductions in FRC alone (such as may occur in obesity and pregnancy) the term "restriction" should not be used.

Restrictive and obstructive

The results (in particular FEV1/FVC and FRC) can be used to distinguish between restrictive and obstructive pulmonary diseases:

Lung volume measurements

Volume Measurements

In this case, gas volumes associated with the respiratory process are the main target of investigation; the principal instruments that have been used so far in the clinical routine and in research activity are

1. **Spirometer:** An expandable chamber whose volume is monitored during inspiration or expiration. The subject is instructed to blow into a conduit

communicating with the chamber; the latter may consist of a bell, a piston, or more often a bellows.

2. **Turbine meter:** Based on the principle that air blown through the inlet produces the rotation of a turbine connected to a revolution counter.

3. **Impedance plethysmograph:** Based on the measurement of resistance (*strain gage plethysmograph*) or of inductance (*inductance plethysmograph*); in both cases, the impedances of an elastic coil wrapped around the subject's chest and one wrapped around the subject's abdomen are monitored during respiration.

4. **Total body plethysmograph:** A kind of sealed telephone booth inside which the subject sits; the pressure inside the box is sensed and converted to volume values¹⁴.

REFERENCE VALUES

Lung volumes are related to body size, with standing height being the most important factor. In children and adolescents, lung growth appears to lag behind the increase in standing height during the growth spurt, and there is a shift in relationship between the lung volume and height during adolescence^{15, 16}. A number of factors must be considered when selecting predictive values for absolute lung volumes including: matching of the reference and patient populations; appropriate extrapolation of regression equations, when considering the size and age range of subjects actually studied; and differences in testing methodology between clinical laboratories and studies from which predicted reference values are derived. Additional information is provided elsewhere¹⁷.

Table No.1: Average lung volumes in healthy adults⁸

S.No	Volume	Value (litres)	
		In men	In women
1	Inspiratory reserve volume	3.3	1.9
2	Tidal volume	0.5	0.5
3	Expiratory reserve volume	1.0	0.7
4	Residual volume	1.2	1.1

Table No.2: Lung capacities in healthy adults⁸

S.No	Volumes	Average value (litres)		Derivation
		In men	In women	
1	Vital capacity	4.8	3.1	IRV plus TV plus ERV
2	Inspiratory capacity	3.8	2.4	IRV plus TV
3	Functional residual capacity	2.2	1.8	ERV plus RV
4	Total lung capacity	6.0	4.2	IRV plus TV plus ERV plus RV

Table No.3: Restrictive and obstructive

S.No	Type	Examples	Description	FEV1/FVC
1	Restrictive Diseases	pulmonary fibrosis, Infant Respiratory Distress, Syndrome, weak respiratory muscles, pneumothorax	volumes are decreased	often in a normal range (0.8 - 1.0)
2	Obstructive Diseases	asthma or COPD	volumes are essentially normal but flow rates are impeded	often low (Asthma can reduce the ratio to 0.6, Emphysema can reduce the ratio to 0.78 - 0.45)

CONCLUSION

This article describes the main target of investigation; the principal instruments that have been used so far in the clinical routine and in research activity includes spirometer, Turbine meter, Impedance plethysmograph (strain gage plethysmograph) or of inductance (inductance plethysmograph) Total body plethysmograph.

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CONFLICT OF INTEREST

None declared.

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