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Lung Volume Measurements-Techniques, Comparison and LabVIEW Based Simulation

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Abstract-- An integral part of complete pulmonary function testing is the measurement of lung volumes. During spirometry some lung volumes can be measured; however, measurement of the residual volume (RV), functional residual capacity (FRC), and total lung capacity (TLC) requires different techniques such as plethysmography, helium dilution and nitrogen washout. FRC is measured by one of three methods. Body plethysmography uses Boyle's Law to determine lung volumes, whereas inert gas dilution and nitrogen washout use dilution properties of gases. Expiratory reserve volume and inspiratory vital capacity are measured after determination of FRC, which allows the calculation of the RV and TLC. The spirometry measurements assess the efficiency of the pulmonary ventilation. In this paper, lung volumes are measured using LabVIEW.

Index Terms— helium dilution method , imaging techniques, lung volume, method comparison, plethysmography, spirometry, static lung volumes.

INTRODUCTION

In particular circumstances, measurements of lung volume are strictly necessary for a correct physiological diagnosis. It employs a stepwise approach to assess ventilation, symptoms and diseases of the respiratory system. The role of lung volume measurements in the assessment of disease severity, functional disability, course of disease and response to treatment remains to be determined in infants as well as in children and adults. Usually, spirometry is preferred. However, additional measurements of lung volumes and resistance offer more specific information and diagnostic accuracy [1].

Subdivisions of lung volume

Static lung volumes are commonly described as either volumes, which are not subdivided, or capacities, which consist of at least two lung volumes. Capacities include total lung capacity (TLC), functional residual capacity (FRC), vital capacity (VC), and inspiratory capacity (IC). Volumes include residual volume (RV), expiratory reserve volume (ERV), tidal volume (VT), and inspiratory reserve volume (Fig 1).

a) The FRC is the volume of gas present in the lung at end expiration during tidal breathing.
b) 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).
c) The maximum volume of gas that can be inspired from FRC is referred to as the inspiratory capacity (IC).
d) The inspiratory reserve volume is the maximum volume of gas that can be inhaled from the end-inspiratory level during tidal breathing.
e) RV refers to the volume of gas remaining in the lung after maximal exhalation (regardless of the lung volume at which exhalation was started).

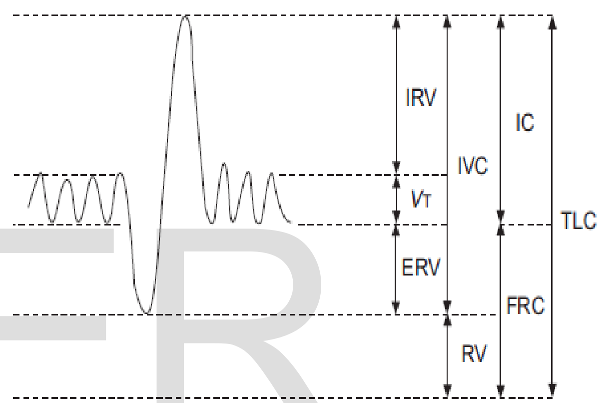

Fig1. Static lung volumes and capacities based on a volume–time spirogram of an inspiratory vital capacity (IVC). IRV: inspiratory reserve volume; VT: tidal volume (TV); ERV: expiratory reserve volume; RV: residual volume; IC: inspiratory capacity; FRC: functional residual capacity; TLC: total lung capacity.

f) The volume of gas inhaled or exhaled during the respiratory cycle is called the tidal volume (TV or VT).
g) The vital capacity (VC) is the volume change at the mouth between the positions of full inspiration and complete expiration.
h) Inspiratory vital capacity (IVC), where the measurement is performed in a relaxed manner, without undue haste or deliberately holding back, from a position of full expiration to full inspiration [9].

GAS DILUTION METHOD

The gas dilution method is the most commonly used method of determining the functional residual capacity of lung. It is based on the use helium that is inhaled in a defined concentration until equilibration is reached, and then measured again in expiration. The test gas consists of air with added oxygen of 25–30% and Helium of 10% (full scale).The degree of dilution allows calculation of the

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volume of gas that has been interacting with the inhaled gas in the lung. The method requires the tracer gas to be inert and insoluble, so that minimal amounts of it diffuse into the lung parenchyma and the blood.

Gas Dilution Principle:

$$V1*C1 = V2*C2$$

If the volume of the circuit system (V1) and the concentration of the tracer gas in it (C1) are known, and the concentration of the gas in expiration (C2) can be measured, then the volume of the circuit plus lung volume (V2) can be derived from the equation above. The lung volume is calculated as V2 - V1.

BODY PLETHYSMOGRAPHY PRINCIPLE

Body plethysmography is based on the principle that the product of pressure (P) and volume (V) in a closed isothermic system of gas is constant (P * V = constant; Boyle's law). It employs either the constant volume or the constant pressure principle. In constant volume measurements, the volume of the body plethysmograph box is constant and pressure changes during resting breathing inside the box. Similarly, with constant pressure registration, the pressures are constant and the volume changes. Constant pressure body plethysmograph boxes do not have to consider body volume and are less sensitive to air leaks.

Modified Boyle's Law:

$$P1\ V1 = P2\ V2$$

P1 = alveolar pressure at time 1,

P2 = alveolar pressure at time 2,

V1 = lung volume at time 1,

V2 = lung volume at time 2.

The product of pressure and volume is constant. When panting against airway occlusion (shutter on the mouthpiece), pressure changes and volume changes in lung volume (expansion/compression) can be recorded, and lung volume (ITGV) can be calculated.

The term TGV (or VTG) refers to the plethysmographic measurement of intrathoracic gas at the time of airflow occlusion. The volume is the compressible gas within the thorax. The term FRCpleth refers to the volume of intrathoracic gas measured when airflow occlusion occurs at FRC [9].

NITROGEN WASHOUT

This technique is based on washing out the N_2 from the lungs, when the patient breathes 100% O_2. In this technique, patient will be asked to breathe through a machine that supplies pure oxygen. No other gases will be present in the air. Then, patient will exhale as long as possible through the machine that will then read the amount of nitrogen in breath. Since nitrogen is not exchanged in the lungs, it sits there until patient exhale. But if breath is too shallow due to respiratory inflammation, it does not escape easily. To calculate the lung volume at the start of washout the initial alveolar N_2 concentration and the amount of N_2 washed out can then be used. The technique originally utilised gas collections for a 7-min period, which is adequate for washout of N_2 from the lungs of healthy subjects. It has the disadvantage that an inaccuracy in the measurement of the expired volume or the final N_2 concentration will cause a significant error FRC, denoted as N_2 FRC when determined using nitrogen washout, is calculated as follows:

$$FRC = \frac{(\text{Volume } N_2 \text{ washed out}) - (N_2 \text{ tissue excretion})}{\text{Initial- final } N_2 \text{ lung concentration}}$$

Formerly, the volume of N_2 washed out was determined by collecting all expired gases during the maneuvre and measuring the total volume and N_2 fraction. New technology allows for continuous measurement of N_2 volume either directly or indirectly via oxygen and CO_2 analyzers [7].

IMAGING TECHNIQUES

For patients who are unable to perform any of the techniques described previously, imaging may represent a useful alternative for measurement of lung volumes.

Conventional Radiographs

Outline the lungs in both anteroposterior and lateral chest radiographs, and determine the outlined areas either by assuming a given geometry or by using planimeters in order to derive the confined volume is the principle of radiographs [8].

Computed Tomography

CTs provide estimates of lung tissue and air volumes, and also estimate the volume of lung occupied by increased density (e.g. in patchy infiltrates) or decreased density (e.g. in emphysema or bullae). A disadvantage of using CT is the high radiation dose.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) offers the advantage of a large number of images within a short period of time. It has advantages of an absence of radiation exposure, despite

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of that the use of MRI for measuring thoracic gas volume will be limited by its considerable cost.

SPIROMETRY

Spirometry is a method of assessing lung function by measuring the volume of air that the patient can expel from the lungs after a maximal inspiration. The standard spirometry maneuver is a maximal forced exhalation (greatest effort possible) after a maximum deep inspiration (completely full lungs). Several indices can be derived from this flow.

• **FVC –** Forced Vital Capacity – the total volume of air that the patient can forcibly exhale in one breath.

• **FEV1** – Forced Expiratory Volume in One Second – the volume of air that the patient is able to exhale in the first second of forced expiration.

• **FEV1 /FVC** – the ratio of FEV1 to FVC expressed as a fraction (previously this was expressed as a percentage).

Values of FEV1 and FVC are measured in litres and are also expressed as a percentage of the predicted values for that individual. The ratio of FEV1/FVC is normally between 0.7 and 0.8 [5][6].

RESULTS

Database of normal respiratory conditions is taken into account and values of all lung volumes and lung capacities are calculated using LabVIEW.

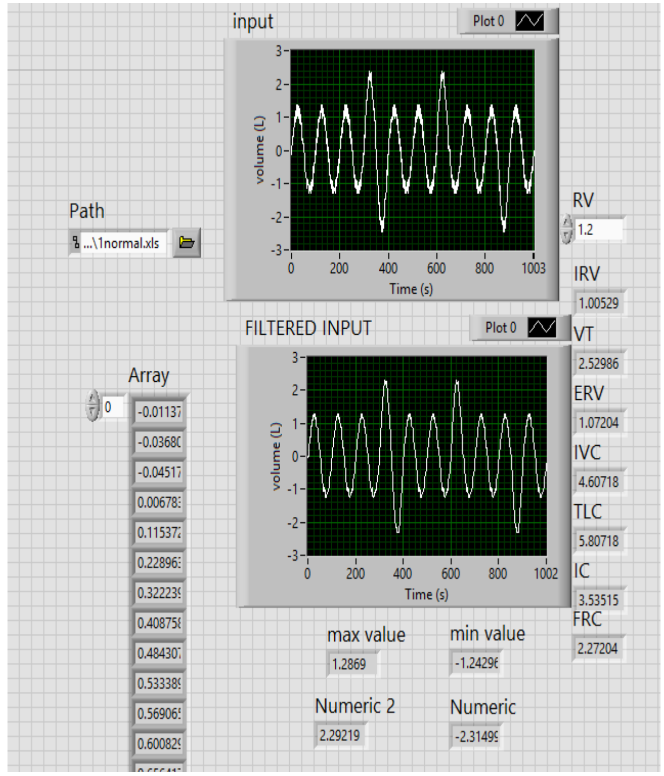

Fig 2: simulation of static lung volumes and capacities.

Expiratory flow is used to calculate the values of FVC and FEV1, the ratio FEV1/FVC(%) obtained is approximately 80 % which is sign of healthy lung(fig. 3).

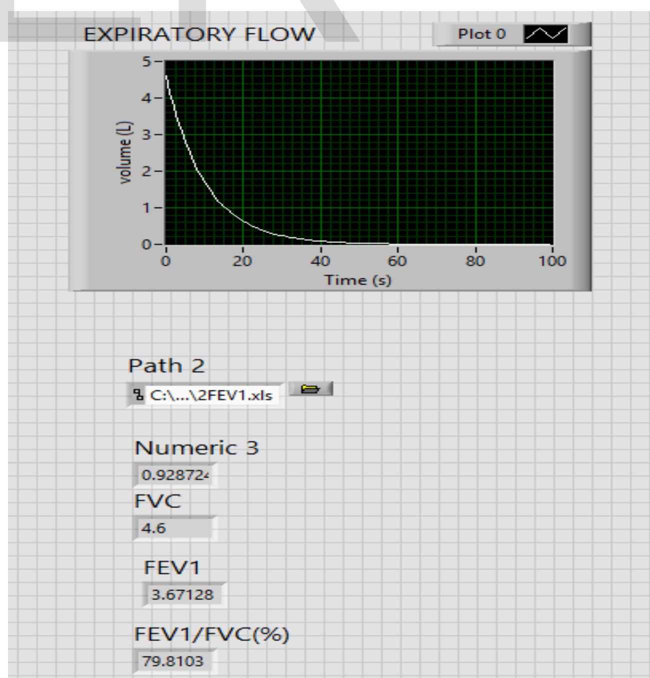

Fig 3: simulated expiratory flow for normal lung.

CONCLUSION

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For the measurement of absolute lung volumes(RV) (which cannot be measured using spirometry) and two capacities (FRC,TLC) requires special techniques such as Body plethysmography, nitrogen washout, helium gas dilution and imaging Techniques.

Spirometry is the best way of detecting the presence of airway obstruction and making a definitive diagnosis of asthma and COPD from the ratio of FEV1 to FVC.

The results obtained in carrying out the simulation with normal conditions show that data and insights in the literature are validated.

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