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Original Article

Plethysmography in Nigeria: An Overview of the Indications, Equipment, Principle, Preparation, Procedure and Interpratation of Results.

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Abstract

Background: Body plethysmography is a non-invasive method used to determine static lung volumes and measure air-way resistance in the lungs. It provides valuable information about respiratory function that cannot be determined by spirometry alone. In Nigeria, where respiratory conditions are a significant health concern, the use of body plethysmography can play a crucial role in improving the quality of care for patients with respiratory issues. However, despite its importance, there is a lack of readily available body plethysmography in Nigeria. This research also describes the current equipment available, the principle, patient preparation, the procedure, the interpretation of results and helps to identify barriers and challenges in implementing body plethysmography in the country. **Main text:** Body plethysmography determines the total volume of gas in the lungs at the end of tidal expiration known as the Functional Residual Capacity (FRCpleth). Total Lung Capacity (TLC) and Residual Volume (RV) are then determined by a linked or unlinked Slow Vital Capacity (SVC) manoeuvre. Plethysmographic measurements are based on Boyle's law. The test usually takes about 15 - 20 minutes to complete. Current guidelines recommend that three or more technically acceptable FRC measurements be made. They must have a repeatability within 5% of each other. Their associated spirometry manoeuvres (SVC) should also meet the acceptability and repeatability criteria. **Conclusion**: Body plethysmography is a highly informative, non-invasive method for obtaining information about lung volumes not determinable by spirometry as well as airway resistance. This test is often used to diagnose conditions such as asthma, chronic obstructive pulmonary disease (COPD), and other respiratory disorders. The lack of lung body plethysmography in Nigeria has serious consequences for the health and well-being of the population. To address this issue, increased funding for healthcare infrastructure and equipment, training programs for respiratory technicians, and collaboration with international organizations are crucial steps that must be taken.

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Introduction

Body plethysmography is a non-invasive method used to assess functional residual capacity (FRC_{pleth}) and specific airway resistance (*sRaw*) as primary measures. In (combination with a maximal expiration and maximal inspiration, total lung capacity (TLC) and residual volume RV) can be determined. Airway resistance (*Raw*) is calculated as the ratio of *sRaw* to FRC_{pleth}(1). *Raw* is a measure of airway obstruction and indicates the alveolar pressure needed to establish a flow rate of 1 L s^{-1}. In contrast, *sRaw* can be interpreted as the work to be performed by volume displacement to establish this flow rate. These measures represent different functional aspects and should both be considered[1]. By measuring changes in pressure and volume within a closed chamber while a patient breathes, body plethysmography can help to identify the presence of airway trapping and hyperinflation and aid the diagnosis of obstructive conditions such as asthma, chronic obstructive pulmonary disease (COPD), and restrictive conditions such as interstitial lung diseases[1-3]. It can be used to monitor the progression of these lung diseases and assess the effectiveness or response to treatment.

Plethysmography allows for a more comprehensive evaluation of respiratory function compared to other pulmonary function tests, such as spirometry[4, 5]. Body plethysmography is also commonly used in research settings to study respiratory mechanics and the effects of various interventions on lung function (2, 4, 5). By measuring the changes in pressure and volume within the lungs, body plethysmography can provide detailed information about airway obstruction, and lung compliance[5,6]. This data can help healthcare providers make more accurate diagnoses and tailor treatment plans to meet the individual needs of each patient[1,5].

In Nigeria, where respiratory conditions are a significant health concern, the use of body plethysmography can play a crucial role in improving the quality of care for patients with respiratory issues[7]. However, despite its importance, there is a lack of readily available body plethysmography in Nigeria. Obaseki et al in 2014 evaluated the quality and capacity for respiratory care in low- and lower-middle-income countries, using Nigeria as a case study and found out that only 3% of Respiratory Physicians have access to plethysmography[8]. This study helps to describe how body plethysmography can be utilized effectively in diagnosing and managing respiratory conditions in Nigeria, and how healthcare providers can improve patient care and outcomes. This research also describes the current equipment available, the principle, patient preparation, the procedure, the interpretation of results and helps to identify barriers and challenges in implementing body plethysmography in the country.

Definitions and Subdivisions of Lung Volume

The term "lung volume" usually refers to the volume of gas within the lungs, as measured by various methodology including body plethysmography (6, 9, 10). The total volume of gas in the lung at maximal inspiration is the Total Lung Capacity (TLC) and can be divided into subdivisions which are either volumes or capacities. The four lung volumes are residual volume (RV), expiratory reserve volume (ERV), tidal volume (V_T) and inspiratory reserve volume (IRV). The lung volumes can be combined to form lung capacities, which include vital capacity (VC), inspiratory capacity (IC), FRC and TLC.

The volume of gas inhaled or exhaled during the respiratory cycle (normal breathing) is called the tidal volume (V_T)(10). Inspiratory reserve volume (IRV) is the maximum volume of gas that can be inhaled from the end-inspiratory lung volume during tidal breathing. Expiratory reserve volume (ERV) is the volume of gas that can be maximally exhaled from the end-expiratory lung volume during tidal breathing (i.e., from FRC to RV). 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) [9,10]. Inspiratory capacity (IC) is the maximum volume of air that can be inspired after reaching the end of a normal, quiet expiration. It is the sum of the tidal volume and the inspiratory reserve volume. The maximum volume of gas that can be inspired from FRC to TLC.

The expiratory vital capacity (EVC) is the maximal volume of air exhaled from the point of maximal inhalation. The VC is the volume change at the mouth between the positions of full inspiration (TLC) and full expiration (RV). FRC is the volume of gas present in the lung at passive end-expiration during tidal breathing, or the sum of ERV and RV. Total lung capacity (TLC) refers to the volume of gas in the lungs after maximal inspiration, or the sum of all volume compartments (RV+ERV+V_T+IRV). Total lung capacity(TLC) is also the sum of IC and FRC or RV and VC[9,10]. The term thoracic gas volume (VTG or TGV) 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 FRC_{pleth} refers to the FRC during relaxed tidal breathing prior to measurement of VTG as obtained by applying a correction if needed for any difference between VTG and FRC.

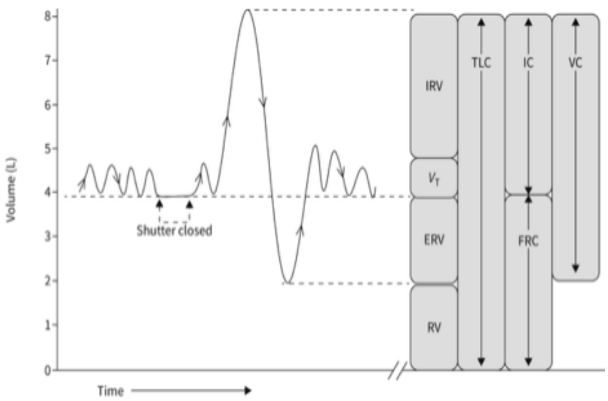


Figure 1: Plethysmography volume-time curve showing different lung volumes and capacities(9).

Principle of Plethysmography

Body plethysmography works by having the patient sit inside a sealed chamber and breathe through a mouthpiece connected to a pressure transducer (see Figure 3) (4, 13). As the patient breathes in and out, changes in pressure within the chamber are measured, allowing for the calculation of lung volume. This information is then used to assess lung function, such as the amount of air the lungs can hold, and the speed at which air can be exhaled. Plethysmographic measurements are based on Boyle's law, which states that, under isothermal conditions, when a constant mass of gas is compressed or decompressed, the gas volume decreases or increases and gas pressure changes such that the product of volume and pressure at any given moment is constant[4,13]. The body plethysmograph is a cabin with a total cabin volume of 700–1200 L. Knowing the specific volume of the box allows for the calculation of volume changes when the subject breathes. To determine RV, subjects are instructed to make several respiratory efforts (similar to panting) at FRC against an occluded airway to ensure there is no airflow(4, 13). The panting-like breathing results in compression and rarefaction of the gas in the lungs. The volume of the air is determined using an equation derived from Boyle's law

$$TGV = -\Delta V / \Delta P (P_B - P_{Vap})$$

where TGV is thoracic gas volume, ΔV is the change in volume in the thorax, ΔP is the change in alveolar pressure (estimated at the mouth), P_B is barometric pressure and P_{Vap} is the water vapour pressure at body temperature and pressure saturated (BTPS)(13).

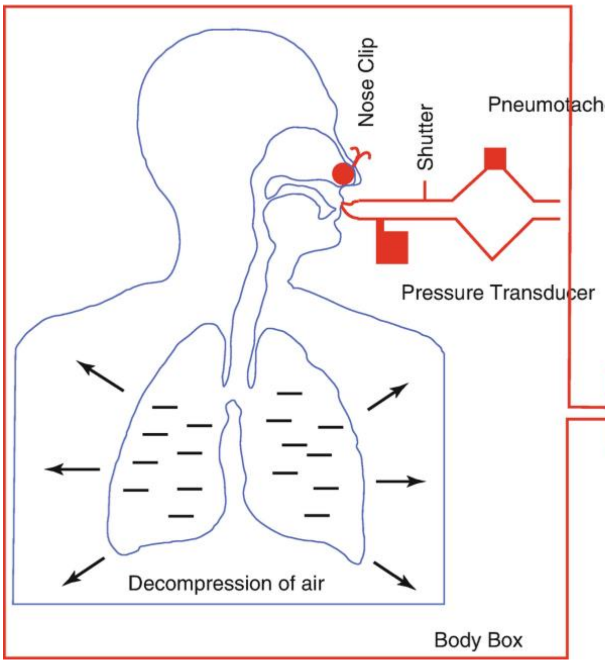


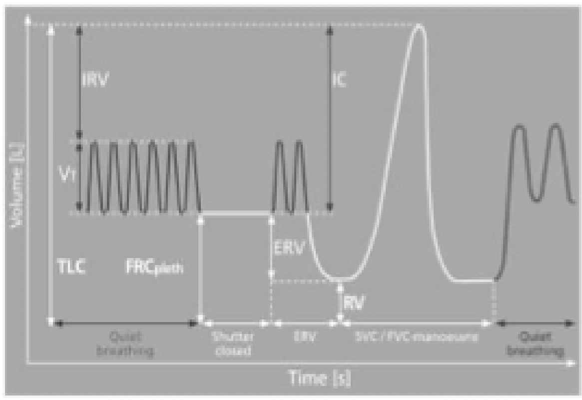
Figure 3. Lung volume measurement in a body plethysmograph taken from Pulmonary Function Tests in Clinical Practice (12)

Equipment

There are about nine manufacturers of body plethysmography (11). The manufacturer of the only functional equipment in Nigeria is COSMED which is located in a private facility in Lagos. The volume of the COSMED available is 873ml. It has a bidirectional intercom for communication between the patient and the operator. The equipment also includes pressure sensors, valves, and a computer that processes and displays the data collected during the test.

The equipment has a transducer capable of measuring mouth pressure of up to ±70 cmH_2O, with a flat frequency response of up to 11Hz. It is generally recommended that the minimum adequate frequency response should be five times the frequency of the signal being measured[9,14]. For a pant at 1 Hz, this means accuracy of the signal at 5 Hz. For panting frequencies slightly above 1 Hz, the minimum acceptable frequency response is 8 Hz[9]. It has a flow measuring device that is used for the measurement of lung volumes and maximal inspiratory and expiratory volumes that meet published standards for the accuracy and frequency response of spirometric devices. The transducer measuring changes in the cabin pressure is capable of accurately measuring a range of up to ±0.1 cmH_2O[9].

Figure 3. The COSMED Plethysmography machine in Nigeria



Title?

Patients Preparation

Explanation of the procedure to patients and obtaining informed consent before the test is crucial. Patients should be instructed to avoid smoking, eating a heavy meal, or engaging in strenuous physical activity before the procedure. It is also important for patients to wear loose-fitting clothing that allows for unrestricted chest movement during the test[4,9]. Additionally, patients may be asked to remove any jewellery or metal objects that could interfere with the results. Proper patient preparation ensures accurate and reliable data during body plethysmography testing[4,9]. Patients should also be informed about the purpose of the test and what to expect during the procedure. This can help alleviate any anxiety or concerns they may have about the test. Informed consent ensures that patients are fully aware of the risks and benefits of the test before proceeding. By following these preparation steps, healthcare providers can ensure that patients are comfortable and ready for body plethysmography testing, leading to accurate and valuable results. Instructing patients on how to breathe during the test is also crucial for obtaining accurate results. Proper breathing techniques, such as taking deep breaths and holding them for a few seconds, can ensure that the measurements taken during the test are consistent and reliable[4,9].

By taking these steps to ensure patient comfort and understanding, healthcare providers can help ensure the success of the body plethysmography test and provide the best possible care for their patients.

Procedure of Body Plethysmography

Detailed steps involved in conducting the test include having the patient sit in a sealed, airtight chamber (Figure 3) while breathing through a mouthpiece connected to a machine that measures lung volume[9,11,15]. The patient will be instructed to breathe in and out in a specific pattern while the machine records their lung function. The test usually takes about 15-20 minutes to complete, during which the patient must remain still and follow the technician's instructions carefully. Once the test is finished, the results will be analysed by a healthcare provider to determine the patient's lung capacity and function[9,11,16].

As a patient enters the box, the seat is adjusted to allow for comfortable sitting position with feet flat on the floor and back straight. The height and location of the breathing valve is also adjusted to allow the patient to breathe without extending their neck. The door of the box is closed for the test. The machine undergoes thermal equilibrium for about 60seconds. The patient starts with normal breathing until a stable end-expiratory level is achieved (usually 3-10 tidal breaths). The patient then gently pants with the hand pressing gently on the cheeks. Panting should be done at a frequency of 0.5 Hz to 1 Hz and pressures between ±10 cmH_20 against a closed shutter at the end of a normal expiration to FRC, creating a pressure change that is measured using a transducer. Next, the shutter opens and the patient performs a linked IC manoeuvre followed by an EVC.

Patients with severe dyspnoea may have difficulty performing linked spirometry immediately after closed shutter panting. To overcome this, the patient can be instructed to stay on the mouthpiece and take two or three tidal breaths after the panting manoeuvre, prior to performing the linked IC and EVC manoeuvres[11]. Three to five trials of panting at the appropriate frequency and pressure should be obtained, which will result in a series of straight lines that are almost superimposed on one another on the plot of plethysmograph pressure versus mouth pressure. At least three values of FRC_{pleth} – calculated using the slope of the line in the plethysmograph versus mouth pressure plot – that are within 5% of each other should be obtained and the mean value should be reported[9,11,16]. The goal is to obtain at least three acceptable FRC_{pleth} values that agree within 5% (i.e., difference between the highest and lowest value divided by the mean is ≤0.05). Three acceptable EVC measurements should also be attained[11].

As the patient is performing the test, the operator sitting outside the box coaches the patient on his or her technique. It is easiest to perform the tests serially without opening the box door and altering the temperature inside; however, the door may need to be opened for the patient's comfort. The door must be shut and temperature stabilised again prior to a repeat measurement.

Figure 4. Volume-time display showing the following sequence: quiet breathing for recording specific airway resistance loops, a period when the shutter is closed for the determination of FRC_{pleth}, and subsequently a period during which the patient performs an expiratory reserve volume (ERV) manoeuvre, followed by a slow vital capacity manoeuvre (SVC) in order to determine inspiratory vital capacity (IVC) and to derive residual volume (RV) and total lung capacity (TLC). Commonly this is followed by a forced vital capacity (FVC) manoeuvre that also yields the forced expiratory volume in 1 s (FEV_1) and the maximum expiratory flows (MEFs) at different lung volumes[1].

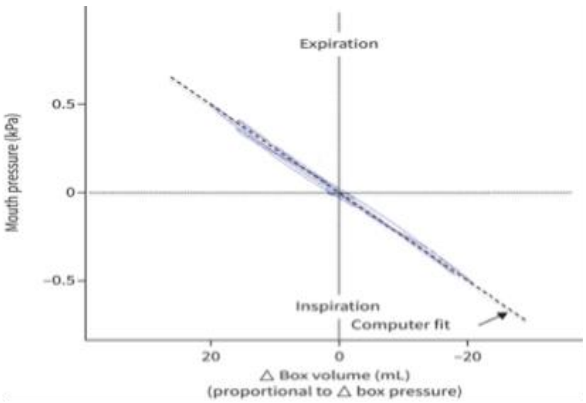


Figure 5: Plot of plethysmograph pressure versus mouth pressure during panting manoeuvre(9).

Quality Control

The accuracy of the flow and volume output of the mouth flow-measuring device should comply with the recommendations made in the spirometry 2019 document[17-19].

The mouth pressure transducer should be physically calibrated daily or prior to use. The plethysmograph signal should also be calibrated daily, using a volume signal of similar magnitude and frequency as the respiratory manoeuvres during testing. Calibration must be performed more frequently when temperature or pressure are changing (e.g., twice a day)[17-19].

At least monthly, or whenever errors are suspected, two healthy nonsmoking reference subjects (biological controls) should undergo body plethysmography. Previously established baseline data from the biological controls should have a coefficient of variation of <5% for both FRC and TLC. Values that differ significantly from the baseline means on the same subject suggest errors of measurement. This process assists the laboratory management team in identifying bias or shifts in clinical results related to an equipment change[17-19].

Figure 4: The Calibration Syringe

Reporting

Selection of Manoeuvres

Three or more acceptable manoeuvres that meet the best FRC repeatability criteria within 5% are obtained, and their associated spirometry manoeuvres should be used to calculate and report FRC and other lung volumes[11,20]. If the operator cannot obtain at least three acceptable and repeatable FRC manoeuvres, all manoeuvres with acceptable or useable FRC and spirometry and meeting the least stringent FRC repeatability within 10% should be used. If two manoeuvres that are acceptable or useable do not meet the least stringent FRC repeatability, specific concerns about a manoeuvre should inform the decision on which one to discard prior to reporting FRC and other lung volumes from a single manoeuvre[11,20].

For body plethysmography, if three grade A manoeuvres meeting the best repeatability are not obtained, the report should include a caution to the interpreter that testing was suboptimal. Acceptability criteria for thoracic gas volume (functional residual capacity) measurement using body plethysmography include stable end-tidal volume prior to shutter closure; closed pants, overlapping straight lines with no thermal drift, straight lines with minimal thermal drift, pant frequency 0.5-1Hz or pant frequency >1.0-1.5Hz or minimal obstruction on spirometry during shutter closure[11,20]. Usable criteria include unstable end-tidal lung volume without significant shift in either direction during pre-shutter closure; while during shutter closure presence of portions of closed pants, portions of overlapping straight pants, parallel straight lines (thermal drift), and pant frequency >1.5–2.0 Hz with no or minimal obstruction on spirometry[11,20].

Unacceptable test shows unstable end tidal volume with significant shift in either direction during pre-shutter closure while during shutter closure, there will be open pants, no straight lines, excessive thermal drift, pants are clipped(mouth pressure transducer range exceeded) and pant frequency <0.5Hz, >2.0 Hz or > 1.5Hz and evidence of significant obstruction on spirometry[11, 20]. Acceptability and usability criteria for spirometry for calculation of residual volume and total lung capacity involves linked spirometry manoeuvre to FRC manoeuvre with SVC ≥ (FVC − 150 mL) if aged >6 years and SVC ≥ (FVC − 100 mL) or (FVC − 10% of FVC), whichever is smaller if aged ≤6 years. Usable criteria involves unlinked spirometry with SVC ≥ (FVC − 250 mL) if aged >6 years and SVC ≥ (FVC − 200 mL) or (FVC − 10% of FVC), whichever is smaller if aged ≤6 years(11, 20). Unacceptable or useable test involves unliked spirometry with SVC < (FVC − 250 mL) if aged >6 years or SVC < (FVC − 200 mL) or (FVC − 10% of FVC), whichever is smaller if aged ≤6 years[11, 20].

Table 1. Body Plethysmographic Measures as Observed in Major Disorders

	FRC	RV	TLC	*Raw*	*sRaw*
Obstructive airway diseases	Normal or elevated	Normal or elevated	Normal	Elevated	Elevated
Hyperinflation	Elevated	Elevated	Normal or elevated	Normal	Elevated
Restrictive disorders	Reduced	Reduced or normal	Reduced	Normal	Normal

Current Limitations

One of the major barriers identified for low body plethysmography utility in Nigeria is unavailability of the equipment in all the public health care institutions where more patients are seen. This makes it is impossible to currently diagnose true restriction and/or distinguish those nonspecific and mixed disorders on spirometry from coexisting isolated obstructive spirometric patterns without estimating TLC. Also, there seems to be a lack of awareness about the utility of the test amongst the physicians and this possibility has influenced the low level of advocacy and engagements of the stake-holders on the need to make the equipment available. There is also lack of personnel who have specialised training in the usage of the equipment in public health care institutions in Nigeria. There is currently no structured programme in the country for training personnel on how to conduct the test effectively.

Recommendations

It is imperative that the Nigerian government prioritize the implementation of ~~lung~~ body plethysmography, a crucial diagnostic tool for respiratory diseases. Without access to this testing method, many individuals may go undiagnosed and untreated, exacerbating the already high rates of morbidity and mortality. It is time for stakeholders in Nigeria to come together and prioritize the implementation of this important technology to ensure that all individuals have access to comprehensive respiratory care. By investing in ~~lung~~ body plethysmography, the healthcare system in Nigeria can better identify and manage respiratory conditions, ultimately improving the overall health outcomes of its population. This advanced diagnostic tool will not only help in early detection of diseases such as asthma, COPD, and pulmonary fibrosis, but also enable healthcare providers to tailor treatment plans more effectively. With the implementation of lung body plethysmography, Nigeria can take a significant step towards reducing the burden of respiratory diseases and improving the quality of life for its citizens.

Conclusion

Body plethysmography is a highly informative, non-invasive method for obtaining information on lung volumes, capacities, and airway resistance. This test is often used to diagnose conditions such as asthma, chronic obstructive pulmonary disease (COPD), and other respiratory disorders. The lack of body plethysmography in Nigeria has serious consequences for the health and well-being of the population. Without access to this essential diagnostic tool, respiratory conditions may go undetected or improperly managed, leading to higher rates of morbidity and mortality. To address this issue, increased funding for healthcare infrastructure and equipment, training programs for respiratory technicians, and collaboration with international organizations are crucial steps that must be taken. By investing in these solutions, Nigeria can improve access to lung function testing and ultimately improve the quality of care for individuals with respiratory diseases.

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