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A comprehensive guide to pulmonary function tests for 1st-year medical students – Simplifying PFTS and their interpretation

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ABSTRACT

Pulmonary function tests (PFTs) constitute a set of non-invasive diagnostic procedures designed to evaluate the functional capabilities of the respiratory system. These tests hold pivotal significance in the identification, tracking, and treatment of diverse respiratory conditions, including asthma, chronic obstructive pulmonary disease, interstitial lung diseases, and restrictive lung disorders. This review article aims to provide medical students with a comprehensive overview of PFTs and their interpretation, offering valuable insights into their crucial role in the diagnosis and management of respiratory ailments.

Key words: Pulmonary function tests; Tidal volume; Inspiratory reserve volume; Expiratory reserve volume; Residual volume; Diffusing capacity of the lung for carbon monoxide; Forced expiratory volume in 1 second; FEVC; Spirometry; Forced vital capacity; Peak expiratory flow rate; Obstructive; Restrictive; Chronic obstructive pulmonary disease

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INTRODUCTION

Pulmonary function tests (PFTs) play a crucial role in respiratory medicine, offering reliable insights into the status of an individual's respiratory system.[1] Widely used in researching respiratory disorders, these tests provide valuable information for diagnosis, assessing airway congestion severity, monitoring lung conditions, evaluating lung growth, early detection of occupational lung diseases, and gauging treatment response. Key ventilator function tests include tidal volume (TV), inspiratory reserve volume (IRV), inspiratory capacity (IC), expiratory reserve volume (ERV), forced vital capacity (FVC), forced expiratory volume in 1st second (FEV1), peak expiratory flow rate, and maximum voluntary ventilation. These parameters offer critical insights into the functionality of the respiratory system. The early detection and diagnosis of pulmonary obstruction at a reversible stage are imperative to prevent irreversible damage.[2] Research has indeed explored the association between PFTs and non-pulmonary conditions, shedding light on the broader implications of respiratory health beyond the lungs.[1,3]

This review on PFTs aims to provide valuable insights and enhancing the understanding of PFTs specifically for first-year medical students. This review aims to help 1st-year medical students learn more about PFTs. By covering various aspects of these tests, it intends to provide a better

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understanding on respiratory medicine during their early medical training.

DESCRIPTION

The PFTs play a key role in clinical practice for evaluating lung function and diagnosing respiratory disorders. For 1st-year MBBS students, gaining a solid understanding of the principles and interpretation of PFTs is crucial. This review aims to offer a comprehensive overview of PFTs, covering indications, techniques, parameters, and clinical significance. It serves as a valuable resource to assist 1st-year medical students in comprehending this fundamental aspect of respiratory medicine.

PFTs constitute a set of non-invasive diagnostic procedures employed to evaluate the functional capacity of the respiratory system. This group of tests holds significant importance in the research realm, contributing to the diagnosis, monitoring, and management of diverse respiratory conditions, including asthma, chronic obstructive pulmonary disease (COPD), interstitial lung diseases, and restrictive lung disorders.[4] Researchers delve into the nuanced aspects of PFTs to enhance our understanding and pave the way for advancements in respiratory medicine. The PFTs aid physicians to evaluate lung functioning, especially when there are concerns about lung health due to factors such as occupational exposures or potential lung damage. These tests help doctors understand the respiratory function of their patients in various clinical scenarios. The national guidelines for measuring and understanding PFTs are regularly revised. The latest guidelines, established by the collaborative efforts of the European Respiratory Society and the American Thoracic Society, were released in 2022.[5] The patient's effort can influence the results of PFTs. These tests alone cannot give a precise diagnosis; it's important to consider the patient's history, physical examination, and laboratory data together to reach a diagnosis. PFTs enable physicians to measure the severity of pulmonary disease, track its progression over time, and evaluate its responsiveness to treatment.[6]

INDICATIONS FOR PULMONARY FUNCTION TESTING

PFTs play a critical role in a variety of clinical scenarios. They are ordered to evaluate symptoms and signs of lung disease, including cough, dyspnea, cyanosis, wheezing, hyperinflation, hypoxemia, and hypercapnia. These tests aid in the diagnosis and monitoring of chronic respiratory conditions such as asthma, COPD, and interstitial lung diseases, as well as assessing the progression of lung disease and monitoring the effectiveness of therapy. PFTs are also valuable in evaluating preoperative patients in selected situations and screening individuals at heightened risk of pulmonary disease, such as smokers or those with occupational exposure to hazardous substances, particularly in occupational surveys. In addition, they are utilized to monitor for possible harmful effects of specific drugs or chemicals, such as amiodarone and beryllium. Overall, PFTs serve as a crucial tool in the assessment, diagnosis, and management of various pulmonary conditions, aiding clinicians in providing optimal care for their patients.

The PFTs are not indicated in asymptomatic patients and may yield ambiguous results, especially in the presence of non-pulmonary illnesses affecting the pulmonary system, such as congestive heart failure.

COMPONENTS OF PFTS

Spirometry

Spirometry is a physiological examination that assesses the capacity to breathe in and out of air in relation to time. Spirometry is a diagnostic tool for many respiratory conditions such as asthma and COPD. It also aids in the monitoring of the progression of different respiratory disorders. Spirometry measures the air moving in and out of the lungs during various respiratory maneuvers.[7] It helps to determine how much air you can breathe in and out and how quickly.

Spirometry is typically done with the person sitting upright. Yet, for specific neuromuscular disorders like spinal cord injury at the level of T6 and above, measurements may be taken in supine position. In such cases, both FVC and FEV1 show reduced values compared to sitting, indicating a higher likelihood of hypoventilation during sleep.[8] The constituents of the respiratory cycle are categorized as lung volumes and lung capacities, where a capacity is the sum of one or more volumes (Table 1 and Figure 1).

Lung volumes and capacities

In spirometry, we focus on the following key measures:

- FVC: During a spirometric maneuver, the patient starts by taking a deep breath. Subsequently, he/she exhales as much and as forcefully as he/she can. The volume exhaled in this manner is known as the FVC.
- The FEV1: The volume of air exhaled in the initial second of the FVC maneuver is called the FEV1. In conditions obstructing the airway, such as asthma or emphysema, this value tends to be lower.
- The FEV1/FVC ratio: This ratio is employed to ascertain whether the respiratory pattern is indicative of obstructive or restrictive.

Table 1: Abbreviations and definitions routinely employed in pulmonary function tests

DLCO	Diffusing capacity of the lung; the capacity of the lungs to transfer carbon monoxide (mL/min/mm Hg)
DLCOc	The DLCO adjusted for hemoglobin (mL/min/mm Hg)
DLVA	The DLCO adjusted for volume (mL/min/mm Hg/L)
DLVC	The DLCO adjusted for both volume and hemoglobin (mL/min/mm Hg/L)
ERV	Expiratory reserve volume; the maximum volume of air that can be exhaled after a normal tidal expiration
FET	Forced expiratory time; the amount of time the patient exhales during the FVC maneuver (seconds)
FEV1	Forced expiratory volume in 1 second; the volume of air that can be forcibly expired in the first second following a maximum inspiration
FEV1/ FVC ratio	Ratio of FEV1 to FVC
FRC	Functional residual capacity; the volume of air remaining in the lungs after expelling a tidal breath=ERV+RV
FVC	Forced vital capacity; the volume of air that can be forcefully expired after a maximum inspiration
IC	Inspiratory capacity; the maximum volume of air that can be inspired from the resting expiratory level=IRV+VT
IRV	Inspiratory reserve volume; the maximum volume of air that can be inspired after completing a normal tidal inspiration
LLN	The lower limit of normal; the lowest value expected for a person of the same age, gender, and height with normal lung function
PEFR	Peak expiratory flow rate; the rate of airflow out of the lungs during a quick forceful expiration
RV	Residual volume; the volume of air that remains in the lungs after a maximal expiration
TLC	Total lung capacity; the total volume of air in the lungs at full inhalation; the sum of all volume compartments (IC+FRC or IRV+VT+ERV+RV)
TV or VT	Tidal volume; the volume of air that is inhaled or exhaled with each breath when a person is breathing at rest
VC	Vital capacity; the maximum volume of air that can be exhaled starting from maximum inspiration, TLC can be measured either as slow vital capacity or forced vital capacity
($FEF_{25-75\%}$)	Forced mid-expiratory flow rate; the rate of airflow during the middle part of a forced expiration
MVV/MBC	Maximum voluntary ventilation/Maximum breathing capacity; the largest amount of air a person can inhale and exhale in 1 min

The major limitation of pulmonary function tests lies in the way they are interpreted, References[9-12]

Diffusing capacity

The ability of the lungs to transfer gas is assessed by the diffusing capacity.[13,14] Efficient pulmonary diffusion occurs when there is an increased surface area for gas transfer, and the blood readily accepts the transferred gas. Therefore, it will decrease in:

- Conditions like anemia can reduce the blood's capability to effectively accept and bind the diffusing gas.
- Conditions (such as emphysema or pulmonary embolism) that reduce the surface area of the alveolar-capillary membrane.
- And the conditions which alter the membrane's permeability or increase its thickness (e.g., pulmonary fibrosis).

For testing diffusing capacity, the gas chosen should be more soluble in blood than in lung tissue. It is best if the lungs, not the blood flow, limit the amount of gas entering. Carbon monoxide is used for this purpose because it strongly binds to hemoglobin and meets these criteria well.

The Table 2 provides simplified DLCO (Diffusing Capacity of the Lungs for Carbon Monoxide) results along with their interpretation and differential diagnosis.

Residual volume (RV), total lung capacity (TLC)

Even after you exhale as long and hard as much as you can, some air will always stay in your lungs, and we call this the RV. If we add this RV to the FVC, we get the TLC.

It is important to highlight that spirometry cannot measure the RV, and consequently, the TLC cannot be directly assessed using this method. Instead, special tests are needed to measure the RV and TLC. These tests may involve breathing in helium, with its concentration measured in the exhaled air to calculate RV. Alternatively, the patient may sit in a sealed booth where pressure is measured while breathing to assess these lung capacities. These measurements often referred to as "static lung volumes" or simply "volumes," contribute additional information beyond what is obtained from spirometry.

In obstructive diseases, measurement of the RV and TLC can reveal signs of air trapping and hyperinflation. Whereas in restrictive diseases, the TLC is used to confirm true restriction and to better measure the extent of restriction.[27]

CRACKING THE CODE: INTERPRETATION OF THE PFTS

In this review article, we aim to simplify the approach to interpret the PFTs, as has been discussed elsewhere.[9]

Demographic data

It is important to verify the patient's demographic information before interpreting PFTs. The test results are provided as actual measurements and as percentages of predicted values. The predicted values and lower limits of normal have been determined by the population studies of individuals without physiologic lung impairment. The regression equations considering variables such as age,

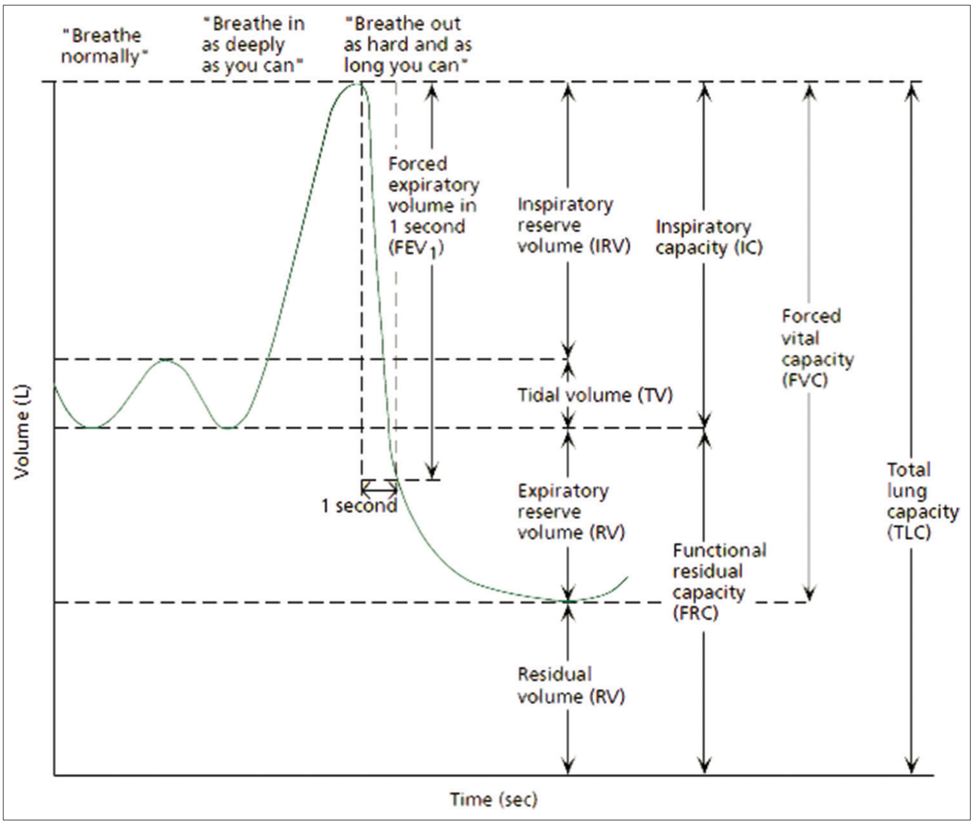

Figure 1: Volume-time spirogram showing different lung volumes and capacities. The important values include forced vital capacity (FVC), forced expiratory volume in 1st second (FEV1), and the FEV1/FVC ratio. It is important to note that residual volume (RV) or total lung capacity (TLC) cannot be measured by spirometry

height, and gender have been established.[28]

Therefore, the predicted values for each patient are based on their age, height, and sex. For instance, the expected values for a 6 feet tall 80-year-old man are lower than those of a 6-foot-tall 50-year-old man. During the test, the health-care provider or technician inputs the patient's details into a computer. While errors are uncommon, the interpreting physician should verify this information, as it is part of the test report. The incorrect patient details can impact the accuracy of the result interpretation.

Evaluation of acceptability and reproducibility

The American Thoracic Society establishes guidelines for acceptability and repeatability.[29] Typically, an FVC maneuver is deemed acceptable when the patient puts in a strong effort, evident by a quick surge in airflow at the beginning of exhalation. A proper complete maneuver needs at least 6 s of exhalation, ending with a flat line in airflow, indicating no more air is being expelled. The report typically includes a flow-time curve and flow-volume loop, enabling visualization of the rapid rise and plateau in flow over time and lung volumes. A proper FVC maneuver reports the highest airflow at the beginning of exhalation and gradually decreases until the end of exhalation (Figure 2 for volume-time curve).

Likewise, airflow rates are highest near the TLC (beginning of the FVC maneuver) and they decrease until the end at the RV (end of the FVC maneuver). This pattern is shown in the flow-volume loop (Figure 2).

We repeat the test 3 times. For it to be reliable, all three FEV1 measurements should be close, within 200 mL of each other, and the same goes for the three FVC measurements. The result reported is from the test with the highest sum of FEV1 and FVC. The results vary if the person does not try their best, does not understand the instructions due to language or hearing issues, or experiences pain during the maneuvers. If the results are not reproducible, they may not reflect the true picture of the patient's lung function.

A step-by-step guide to interpretation

Figure 3 summarizes the step-by-step guide to interpreting the results. The strategy involves recognizing the pattern and then classifying the severity of the condition.

Does the pattern indicate obstruction, restriction, or normal function?

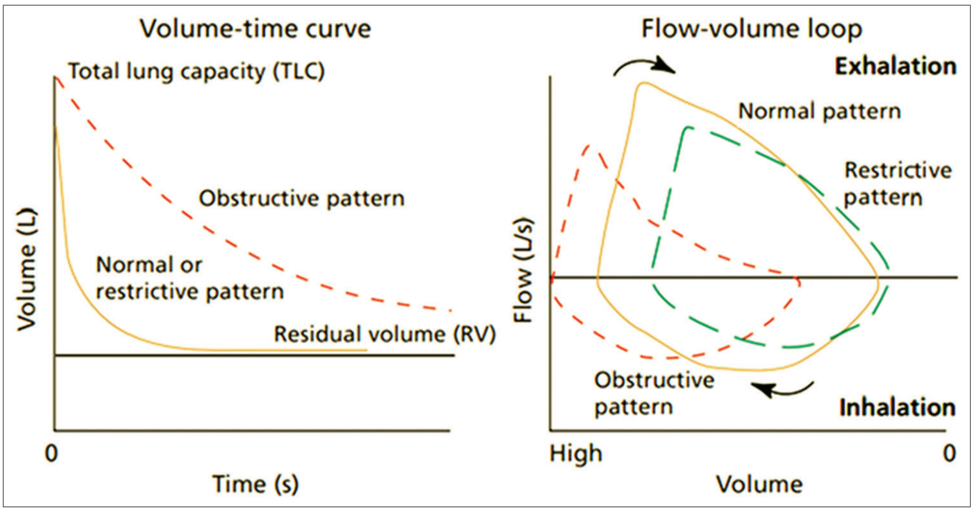

Figure 2: Volume-time curve and flow-volume curve

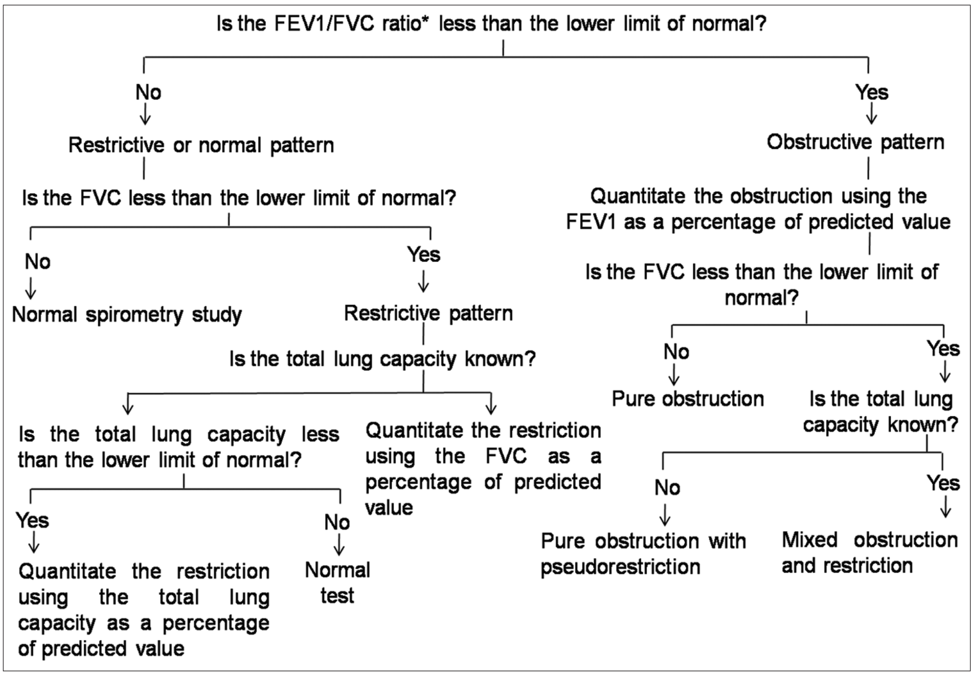

Figure 3: Quick guide for interpreting pulmonary function tests. *FEV1: Forced expiratory volume in 1 s, FVC: Forced vital capacity. Adopted from reference[9]

The process starts by checking the FEV1/FVC ratio. If the ratio is below the normal limit (provided in the test report), it indicates an obstruction – meaning that the FEV1 has decreased more than the FVC. If the FEV1/FVC ratio is above the normal limit, it could mean that the spirometry is normal or there might be a restrictive defect. In such cases, focusing on the FVC helps. If the FVC is below the normal limit, it suggests a restrictive defect. To confirm, TLC (if measured) is checked, and if it is less than the predicted normal limit, it confirms the presence of restriction. The obstructive and restrictive lung patterns are given in Table 3.

The spirometry is often repeated after administration of a bronchodilator. A substantial bronchodilator response is defined as an increase in FEV1 or FVC of at least 12% and 200 mL from pre-bronchodilator values.[30]

Assessment of the severity of the defect?

To assess the degree of obstruction, clinicians need to take note of the patient's FEV1 as a percentage of predicted FEV1 (Table 4). Likewise, to assess the degree restriction, clinicians need to check the patient's FVC or TLC as a percentage of the predicted value. If the FEV1/FVC ratio is lower than the lower limit of normal (LLN), the degree of obstruction is determined by the percentage of FEV1

Table 2: Interpreting DLCO results – A guide to differential diagnosis

DLCO results	Differential diagnosis
High DLCO	Asthma, left-to-right intracardiac shunts, polycythemia, and pulmonary hemorrhage
Normal DLCO with restrictive pattern	Kyphoscoliosis, morbid obesity, neuromuscular weakness, and pleural effusion
Normal DLCO with an obstructive component	α1-antitrypsin deficiency, asthma, and bronchiectasis, chronic bronchitis
Low DLCO with restriction	Asbestosis, berylliosis, hypersensitivity pneumonitis, idiopathic pulmonary fibrosis, Langerhans cell histiocytosis (histiocytosis X), lymphangitic spread of tumor, miliary tuberculosis, sarcoidosis, and silicosis (late)
Low DLCO with obstruction	Cystic fibrosis, emphysema, and silicosis (early)
Low DLCO with normal pulmonary function test results	Chronic pulmonary emboli, congestive heart failure, connective tissue disease with pulmonary involvement, dermatomyositis/ polymyositis, inflammatory bowel disease, interstitial lung disease (early), primary pulmonary hypertension, rheumatoid arthritis, systemic lupus erythematosus, systemic sclerosis, and Wegener granulomatosis (also called granulomatosis with polyangiitis)

Interpretation: High = >120% of predicted; Normal=LLN to 120% of predicted; Low (mild decrease) = >60% of predicted and less than LLN; Low (moderate decrease) = 40–60% of predicted; Low (severe decrease) = <40% of predicted. If the laboratory does not report LLN, observational studies indicate that the LLN for men is approximately 80%, and the LLN for women is approximately 76%. DLCO: Diffusing capacity of the lung for carbon monoxide, LLN: Lower limit of normal. References[15-26]

Table 3: Obstructive and restrictive patterns

Measurement	Obstructive Pattern	Restrictive Pattern
FVC	Decreased or normal	Decreased
FEV1	Decreased	Decreased or normal
FEV1/FVC ratio	Decreased	Normal
TLC	Normal or increased	Decreased

FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 s, TLC: Total lung capacity. Reference[27]

Table 4: Grading of obstruction and restriction severity

FEV1/ FVC ratio	Obstruction grading	FEV1/FVC ratio	Restriction grading
<LLN to 60% Mild	Mild	<LLN to 60%	Mild
59–40%	Moderate	59% to 50%	Moderate
39–30%	Severe	49% to 35%	Severe
<30%	Very Severe	<35%	Very Severe

FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 second, LLN: Lower limit of normal, References[28]

compared to its predicted value, following the obstruction algorithm (Table 4). Likewise, for restriction, if the FEV1/ FVC ratio is normal and the TLC is below the LLN, follow the below restriction algorithm (Table 4).

CLINICAL PEARL

Remember: Obstruction, 60/40/30, Restriction, 60/50/35.

In some cases sometimes, even if the FEV1/FVC ratio looks normal, there might still be an obstruction. In such cases, using a bronchodilator, assessing airway resistance, or doing a positive methacholine challenge test can provide additional insights. The bronchodilator response is positive when either FEV1 or FVC increases by ≥12% or ≥200 mL. Moreover, a large response post-bronchodilator usage is indicative of:

- Rapid decline in lung function
- Possibility of severe exacerbations
- Higher risk of quick decline and potential complications

It is interesting to note that in some cases where PFT results appear normal, yet the physician maintains a suspicion of exercise- or allergen-induced asthma, the subsequent course of action involves bronchoprovocation. This may encompass procedures such as a methacholine challenge, a mannitol inhalation challenge, exercise testing, or, at times, eucapnic voluntary hyperpnea testing. These provocative tests aim to elicit bronchial hyperresponsiveness, aiding in the identification and confirmation of asthma even in the absence of overt abnormalities in routine PFTs.[26,31]

To appreciate the clinical application of PFT's tests in diagnosing and managing respiratory diseases, it is essential to demonstrate some clinical case scenarios to students where PFTs are used. The case scenarios will not only facilitate a deeper understanding of the theoretical aspects of PFTs but will also encourage critical thinking and the application of acquired knowledge in clinical contexts by future practitioners.

CONCLUSION

PFTs are crucial for diagnosing various lung conditions and uncovering non-pulmonary diseases. Primary care physicians need a fundamental understanding of PFT interpretation to diagnose respiratory symptoms effectively. When interpreting PFTs, the primary focus should be on the identification of the pattern of physiological impairment rather than making an immediate diagnosis. Once the pattern is recognized, it equips the knowledgeable physician with crucial information to diagnose and address pulmonary issues effectively. It is important to mention that if a patient has previous PFT results, comparing them with the current ones can help assess the disease progression or the impact of treatment.

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