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Role of Advanced Imaging Techniques in Detection of Respiratory Diseases

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ABSTRACT

Advancement in imaging modalities allows the functional evaluation of pulmonary region in patients with respiratory illness. This review represents the present state of the art in respiratory imaging & incorporates recent developments in medical imaging technology when combined with machine learning skills for pulmonary diagnosis and treatment. Modalities like CT have come up with advances in imaging techniques that include Parametric response mapping & jacobian determinant that allow functional evaluation of small airway disease and local volume changes among expiration & inspiration phases, followed by dynamic CT, which combines with xenon and allows visualization of congenital hyperlucent lesions in the lung and areas of poor ventilation in COPD patients. Imaging of the pulmonary region in MRI has been made possible by using fluorine-19 gas ventilation and xenon-129 hyperpolarized gas, as they have the capability to evaluate global and regional patterns of lung ventilation directly and in addition to it development of advance MR sequences for lung imaging. DCR has already been concluded in clinical practice in Japan, as it has less radiation exposure as compared to chest radiography and can detect diaphragmatic movement, which is a key factor to assess in patients undergoing COPD. SPECT can accurately identify ventilation/perfusion (V/Q) mismatches and detect pulmonary embolism patients' situations where ventilation/perfusion is amazingly identical, such as the pulmonary infarction zone. LUS and EIT can easily determine conditions like pulmonary edema, pneumothorax, and acute respiratory distress syndrome, while EIT monitors lung perfusion that reflects tissue health in the early stages of pulmonary illness.

Keywords: *K-space techniques; Respiratory gating; Low attenuation area; ZTE; UTE; Ventilation; Perfusion; Artificial intelligence; Machine learning; Parametric response mapping; COPD; Small airway disease; Low attenuation area; Silent zone; Gadolinium perfusion; Lung sliding; Fiber gating; Charge-coupled devices*

1. INTRODUCTION

Latest developments in technologies in medical imaging, when combined with machine learning skills, are opening the door for detailed examinations of the functioning of lungs and medical results regarding people suffering from breathing-related conditions. By using diverse medical imaging modalities including magnetic resonance imaging (MRI),computed tomography (CT) & positron emission tomography (PET) these revolutionary developments are capable of analysing quantitative information via using powerful algorithmic computation called "radiomics" (1–3). Implementing innovations into clinical procedures might be difficult for many healthcare practitioners. Spirometry is a primary tool used by pulmonologists to assess lung function. Pulmonary function tests inspect breathing and gas exchange, but cannot diagnose certain diseases that cause impaired functioning. Performing these tests may be challenging for individuals with weak, severe, or deteriorating illnesses. During the spread of coronavirus disease, the experience gathered has demonstrated the role of contactless techniques like functional imaging to find out the proper functioning of the respiratory region.

The most recent advancements in chest CT and MRI imaging provide dynamic & three-dimensional images in the region of the chest, detecting minor pathological alteration in the parenchyma of lungs, chest wall, airways, & circulation(4–9). Increasing the physiological investigation of the lungs towards the diagnosis of pulmonary disease (10,11). Recent research shows patients who are experiencing respiratory failure, their pulmonary function can be evaluated by combining traditional and innovative imaging techniques that include ultrasound, electrical impedance tomography (EIT), and dynamic chest radiography(12–14).

2. FUNCTIONAL IMAGING TECHNIQUES BASED ON CT

Computed tomography-based methods are being established to recognize morphologies & anticipate the clinical consequences for afflictions like Chronic Obstructive Pulmonary Disease (COPD). Among these approaches, the area having low-attenuation called low-attenuation area denoted as (LAA) beneath a designated hounsfield unit denoted as (HU) in which threshold was thoroughly & extensively studied. The proportion of LAA under 950 (HU) inside inspiratory computed tomography (%LAA-950) indicates emphysema (15) & forecasts airflow obstruction through spirometry, outcome in COPD & quality of life (16–18). Nevertheless, a discrepancy remains among CT-observed emphysema and spirometric airway obstruction, regardless of their statistical relationship (18). Furthermore, emphysema severity on static CT scan can fluctuate considerably at the identical COPD stage, & severity in obstruction of airflow is independent of emphysema extent (19). As a result, techniques of imaging relying on static single-volume computed tomography, together with LAA, have constraints regarding functional measurement and are thus inadequate for the evaluation of COPD.

The functional evaluation of pulmonary disease is determined by the most modern techniques of imaging that use parametric response mapping & jacobian determinant, which is produced in combination with paired expiratory & inspiratory, and computed tomography images. Overall Jacobian determinant is a biomechanical imaging technique that assesses the changes of local volume among inspiration & expiration in images obtained from CT (20).

The value of Jacobian determinant starts at 0 and end up to the infinity, with values (>1) denoting expansion and those (<1) denoting contraction of local volume of lung. Values of Jacobian determinant have a powerful connection with obstruction of airflow (21) & determined through spirometry and can strengthen the relationship among emphysema on static CT & obstruction of air in patients suffering from COPD(22). Mechanically injured pulmonary regions can also be detected by Jacobian determinant within two millimetres of emphysema, during breathing those are prone to mechanical forces and have been connected with the cumulative drop in forced expiratory volume (FEV) in 1s (23). The functioning of the pulmonary region & quality of life for patients suffering from COPD is determined by this biomechanical metric.

On the other hand, parametric response mapping is a technique i.e. dependent on the voxel-based method that uses coupled inspiratory and expiratory CT to provide data that is a quantitative functional evaluation of small airway illness (also known as "functional Small Airway Disease (fSAD)"). Subsequently, depending on each voxel's HU value in expiratory & inspiratory scans of CT. The fields of the lungs are divided into 3 categories, as shown in (fig 1). PRM Normal (> -950 HU inside inspiratory CT & > -856 HU inside expiratory CT, showing the parenchyma of lung normal), PRM^{fSAD} (> -950 HU inside inspiratory CT & -856 HU or lower inside expiratory CT, suggesting fSAD), & PRM^{EMPH}(Emphysema) (-950 HU or lower inside inspiratory CT and -856 HU or lower inside expiratory CT, which indicates emphysema (24). Researchers have shown that fSAD is an in-direct biomarker of pathology related to illness of small airway showing diameter (<2mm), which indicates an initial pathological alteration & a key location of obstruction in airway in COPD (25–27). A new study suggests that small airway disease is an early sign of emphysema, as evidenced by the progression of PRM^{fSAD} to PRM^{Emph} (28). PRM^{fSAD} is linked to a yearly reduction in FEV1 (Forced Expiratory Volume) in those who smoke with and don't suffer from COPD. Particularly, the reduction in the functioning of the lung is gradually higher in earlier COPD (29), suggesting that fSAD has significance as a biomarker for prior medical treatment.

PRM^{fSAD} delivers investigative as well as predicting information for patients undergoing a condition called bronchiolitis obliterans (BO) following lung or hematopoietic stem cell transplantation (30,31). fSAD in MacLeod/Swyer-James syndrome, an extremely uncommon disorder characterized by unilateral hyper lucency induced by post-infectious obstruction of the airway and pulmonary vascular hypoplasia can also be detected by PRM (32). According to a new study, PRM^{fSAD} is associated with increasing asthma symptoms (33).

These advanced functional imaging methods can analyse individual patients and provide personalized treatment plans. Further potential studies can establish functional imaging metrics as biomarkers that may assist in identifying the individuals who might benefit from earlier intervention.

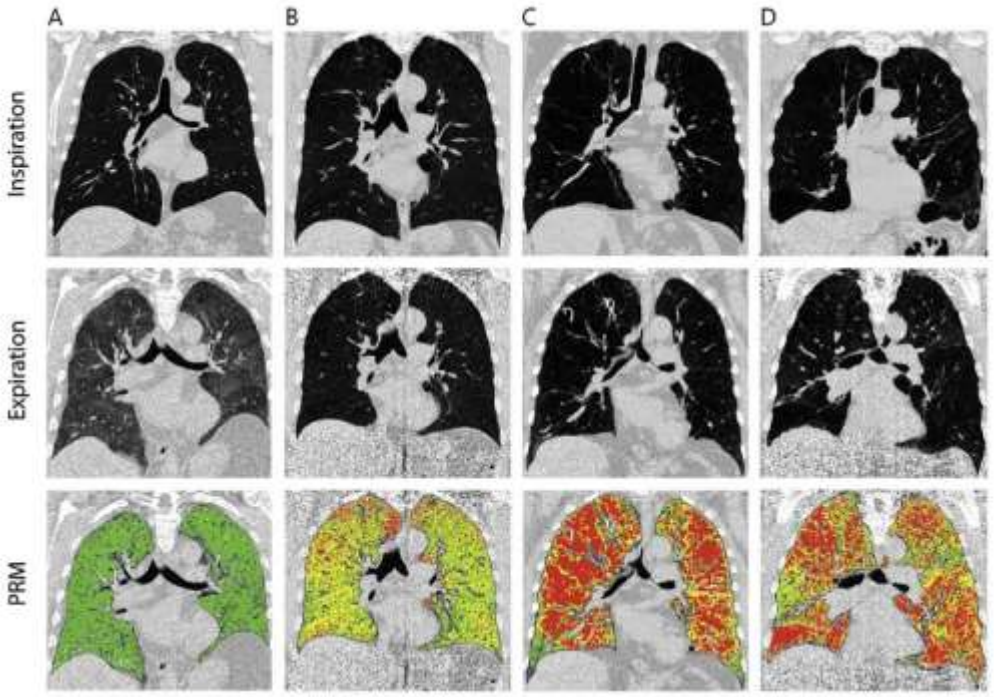


Figure 1: Image showcasing PRM (Parametric Response Mapping) identifies COPD phenotypes. PRM distinguishes (PRM^{fSAD}) from (PRM^{EMPH}), which can be seen in the example pictures of PRM and matched expiratory & inspiratory and CT scans of 4 individuals with fluctuating degrees of COPD. The tissue of the lungs is characterized into 3 types; Ordinary tissue (green), emphysema (red) & fSAD `(yellow) (24).

3. IMPLEMENTING CHEST CT FOR ASSESSING THE CHEST WALL, PULMONARY CIRCULATION, INTERSTITIAL CHANGES, AND AIRWAYS

Evaluating airway shape and function accurately is crucial for better understanding the pathogenic pathways and illness management because three-dimensional computed tomography (CT) allows in-vivo & simpler visualization of the airways and is commonly employed in research & clinical sectors. Previous histology investigations show the structural and functional relationship between diseases such as COPD (34) and asthma (35). Parameters like $\%FEV_1$ were compared with distal and proximal airways. The authors concluded that in COPD, distal airways (greater than 2 mm in diameter) exhibited a stronger correlation with %FEV1 in comparison with proximal airways. Asthma did not exhibit the same correlation of distal airways.

Ultra-high-resolution computed tomography, which was just introduced, makes it easier to see airways, lung nodules, arteries, honeycombs & emphysema through increasing spatial resolution applying 1024×1024 and 2048×2048 matrices, the resolution can reach 0.14mm/pixel and absence of any increment in radiation dose (36,37). Ultra-high resolution CT scans provide better measurement of small airways compared to conventional CT scans. Ultra-high-resolution CT has made it possible for the direct examination of the 'silent zone,' has been made possible by it, which is characterized by narrow airways relative to lung size (38). Due to these advantages, conditions like dysanapsis (39), can be evaluated easily, which has been associated with obstructive lung disease susceptibility. It can be measured directly with the help of CT scans by measuring the diameter of airways with lung size (40).

Pulmonary arterial pruning reduces the percentage of small artery volume to total artery volume inside lungs. It is defined by the constriction and loss of small pulmonary arteries, which can result in increased pulmonary arterial resistance and poor outcomes. CT imaging can be used to examine pulmonary artery pruning in a non-invasive manner. According to research, pulmonary artery pruning is associated with faster emphysema advancement, a faster fall in the FEV to FVC (Forced Vital Capacity) ratio, higher pulmonary artery pressures, right ventricular dysfunction, and increased mortality. For COPD, pulmonary arterial pruning (arterial vessels < 5mm) is linked with the elevated volume of the right ventricle on CT scans along with the restricted capacity of exercise, & inadequate clinical outlook (41). In addition, in critical asthma, overall epicardial heart ventricular volume measures were more frequently less than in mild/moderate asthma and were associated with frequently occurring episodes of asthma, both retrospectively and prospectively (42).

Future Direction

In radiology Artificial intelligence (AI) has become an important role, offering accurate and specific results. As a result,

when combined with technical application, these important techniques have the capability to increase the recognizing the pathophysiology associated with the lung disorders & how they can be treated.

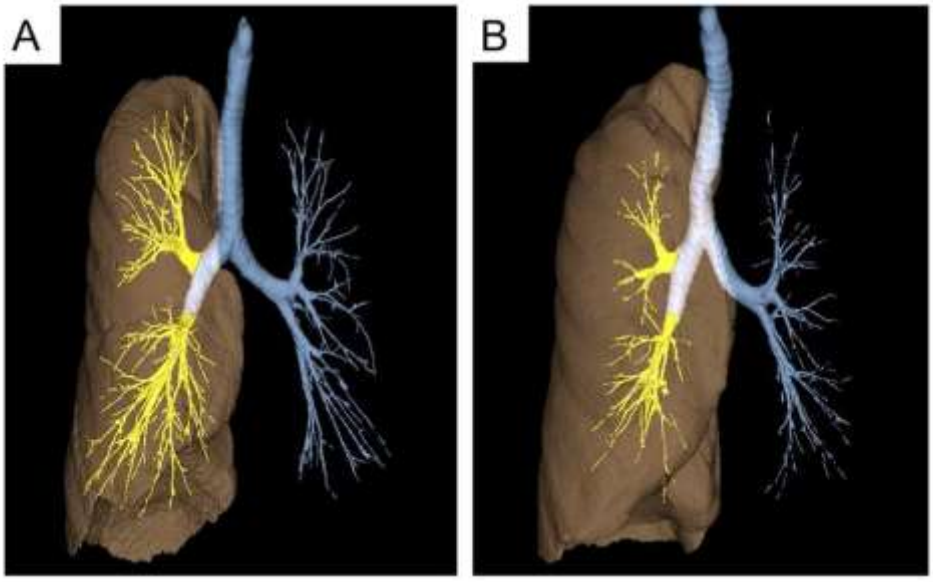


Figure 2: Two COPD cases can be seen as three-dimensional (3D) renderings of the tracheobronchial tree & right lung. Case A: Measurable (%FEV1) is 81%& height is 167 cm. Whereas Case B: %FEV1 is 32%, height is 167 cm. Case B had a reduced volume of airway tree & a bigger capacity of the lung, which led to a significantly lower airway volume % (43).

4. RESPIRATORY FUNCTION AND DYNAMIC COMPUTED TOMOGRAPHY

Dual-energy CT can easily examine emphysema and airway illness, together with functional evaluation of perfusion & ventilation by degradation of tissue. Utilizing Xenon with dual-energy computed tomography using a single breath hold approach can show ventilation inside patients with COPD. (44)

Xenon (30%) and oxygen (70%) are given to a patient through inhalation in combination with xenon gas rebreathing apparatus and a face mask (fig 3) shows that a mask has been attached to the face of a child using hands for a small & medicated youngster, while a prepared and older child is held using elastric straps. The concentrations of exhaled xenon, carbon dioxide, and inhaled xenon and oxygen can be measured through a xenon ventilator. To keep up with the physiological fluctuations of respiration, xenon was absorbed until the concentration of exhaled xenon gained about 25-30% (during the phase of wash-in). At this concentration of breathed xenon, the bulk of the normal lung is estimated to be 30% filled with xenon gas. To avoid inhaling xenon (during the wash-out phase), 100% oxygen was inhaled throughout the remainder of the trial (45).

Xe enhanced dynamic dual-energy computed tomography imaging can also detect areas with inadequate ventilation in COPD & congenital abnormalities like hyperlucent lung lesions (45,46). Evaluation of pulmonary perfusion can be done by contrast study and non-contrast study by utilizing computed tomography. While xenon-enhanced CT is currently considered a routine approach for measuring ventilation in regional lungs (47–49). In addition to addressing pulmonary vascular anomalies, such approaches can be utilized to monitor tumor perfusion concerning therapy success in those diagnosed with lung cancer. (50).

They employed four-dimensional computed tomography geometry, boundary conditions & distorted zones of vector to assess impaired function in patients with COPD. Four-dimensional (4D) dynamic ventilation. CT scanning can assess respiratory movements among pulmonary lobes, which are reduced in individuals with severe COPD (51,52).

Dynamic-ventilation CT scans reveal that patients with COPD had a lower heart size & abnormal cardiac compression during the phase of expiration compared to non-COPD smokers (53). Lateral decubitus position in 4D-CT can be used to assess the localized pleural adhesions in region of apical of COPD patients. While dynamic-ventilation CT images acquired in a lateral position reveal restricted airflow & are related to improved ventilation in the non-dependent lung, the earlier collapse of the airway, and lower synchronization among the airway & movements of the lung inside the dependent lung (54,55).

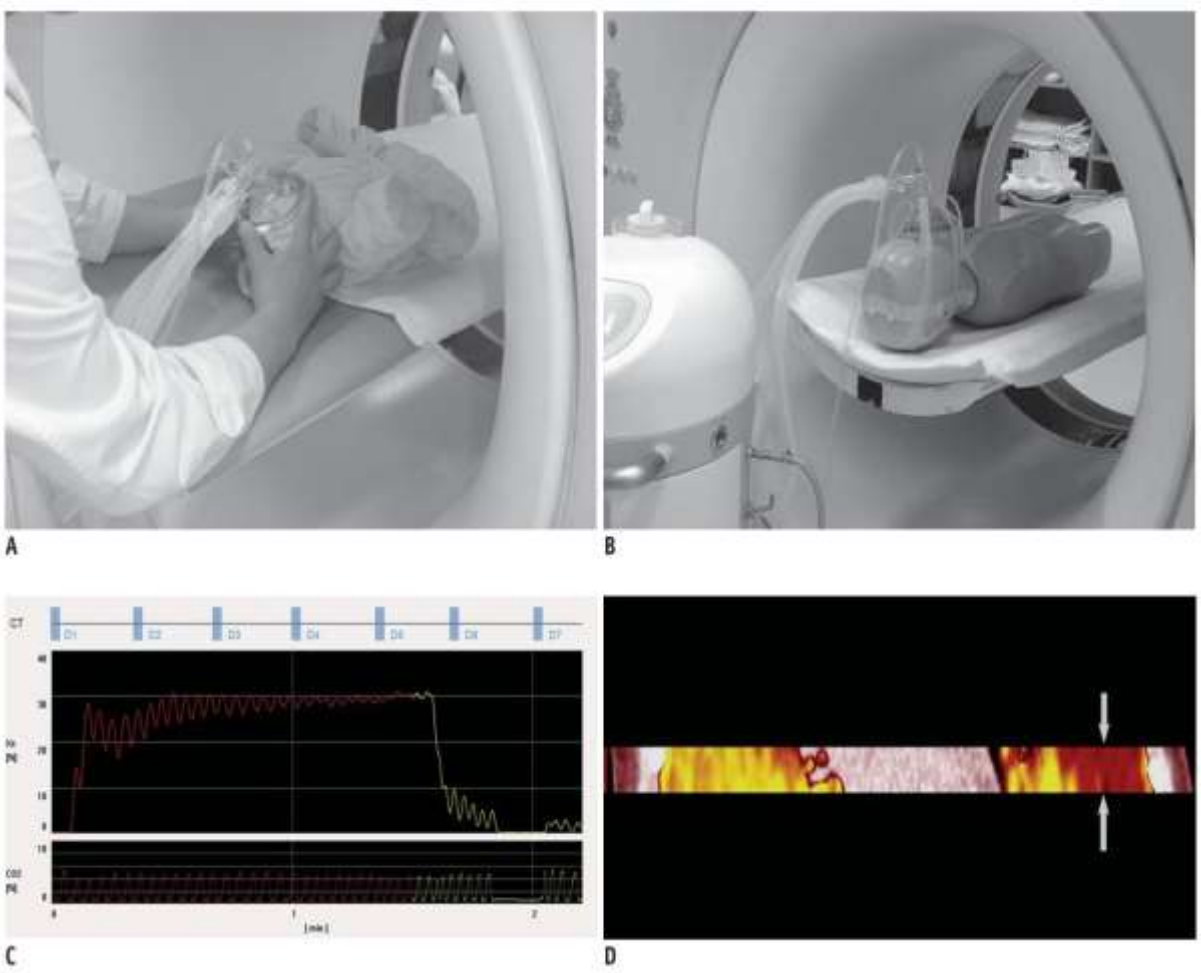


Figure 3: Demonstrating the techniques of imaging in Xenon enhanced DECT. (A) Shows examination of CT for medicated & young child (doll for demonstration is taken) in which a face mask is attached using hands. (B) Image representing a 5-year-old phantom for a demonstration that is held using a face mask with an elastric strap as it is a cooperative child. (C) Graph showing the phases of dual-energy CT i.e. wash in phase in color red while the wash-out phase can be seen in color yellow in a protocol ranging from D1-D7 from which D1 is a baseline & wash-in phase begins from D2 and ends at D5 while the wash out can be seen in D6 and D7 scans. (D) Arrows (defects of ventilation) are seen with maximum enhancement of xenon in the left lung in a dual-energy spiral scan (45).

5. MRI AND PULMONARY FUNCTION

Magnetic resonance imaging (MRI is a significant imaging technique as it offers its aids, that includes, exceptional soft tissue contrast, being free of ionizing radiation & the ability to gather information about functionality. Although it has numerous advantages, MRI of the chest isn't as widely utilized as computed tomography for identifying thoracic illnesses due to many barriers to deployment in clinical settings. The main obstacles involve innate physical constraints, particularly inhomogeneity of magnetic field, proton deficiency & motion artefacts, while operator-related barriers, including inadequate chest MRI training, minimal thoracic radiologist expertise, and lack of standardized protocols, MRI interpretation confidence & the different sequences advocated by the producers. In initial decade of this century, specialized MRI pulse sequences were introduced significantly improving the quality of images and defect identification capabilities for pulmonary disorders. As a result, there is increased anticipation about the evaluation capability and importance of MRI in the pulmonary region (56).

5.1 Contingencies for employing MRI of the pulmonary region in clinical settings and effective techniques for eliminating them.

Insufficient proton concentration in the pulmonary system

The pulmonary system possesses a considerably lower density of proton compared to the different soft tissues in the mediastinum & chest wall since they are roughly 800 grams of tissue & contain 4-6 Litres of blood. Moreover, inhomogeneities of local field across the tissue-air along with liquid-air interfaces occur due to the presence of air in the lungs, resulting in the shortening of T2* (57,58). As a result, most MRI sequences show the parenchyma of the lung as dark

or almost black. Recent approaches, such as zero echo time (ZTE) & ultrafast echo time (UTE) sequences in MRI, provide promising solutions in the parenchyma of the lung for loss of signal (59–61).

Respiratory motion artefact-

Reducing respiratory motion is crucial for the accurate interpretation of MRI scans. Implementing breath-holding strategies during the acquisition of data will successfully remove respiratory motion artefacts (fig. 4). Limiting the duration of acquisition for MRI sequences of chest is recommended to maximize images quality, as healthy individuals are capable of holding their breath for about 20 seconds. Variations can be made for patients who cannot hold their breath for 20 seconds or if the sequence is not limited to this time frame. A possible approach is to divide the volume of tissue across smaller stacks to allow for a quicker acquisition period. On the other hand, elevating the number of combinations per sequence distributes slices among numerous repetitions, resulting in shorter breath-holding intervals. Respiratory motion artefacts can be reduced using radial k-space sampling through oversampling and updating the center through overlapping spokes (fig 5) (62). Techniques such as StarVIBE (63) & PROPELLER (64) use periodically rotating overlapped lines that are parallel for better reconstruction & Use radial sampling to create motion-insensitive images.

Respiratory gating is a technique that helps patients who have respiratory problems incapable of holding their breath. This approach uses respiratory-navigated MRI sequence & external pneumatic belt to capture images during specified stages of the breathing cycle, typically toward the end of the expiration phase (60,65,66).

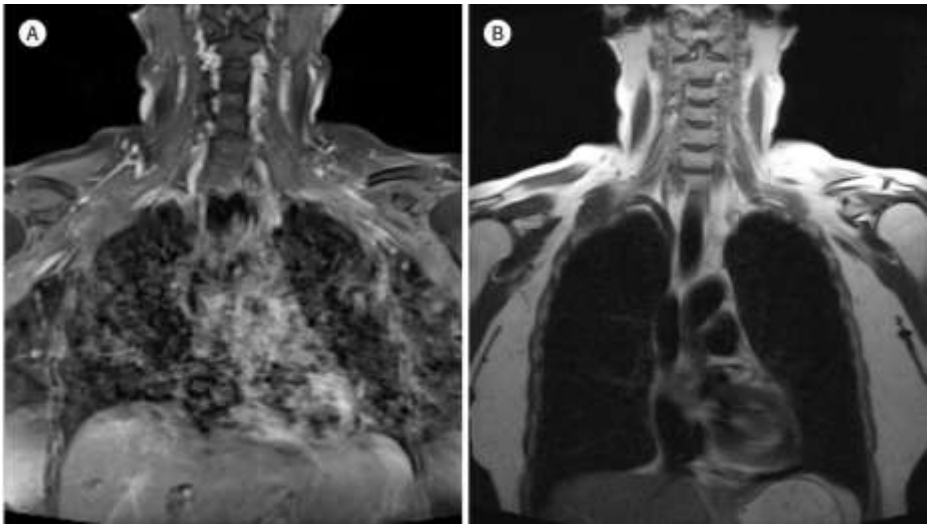


Figure 4: Represents an MRI scan of the chest region of female patient 53-year-old showing artefacts of respiratory motion on cor T1-weighted TSE image. (A) Fade on the cor T2-weighted single shot FSE image. (B) Elimination of respiratory motion by implementing cardiac gating & breath hold techniques (62).

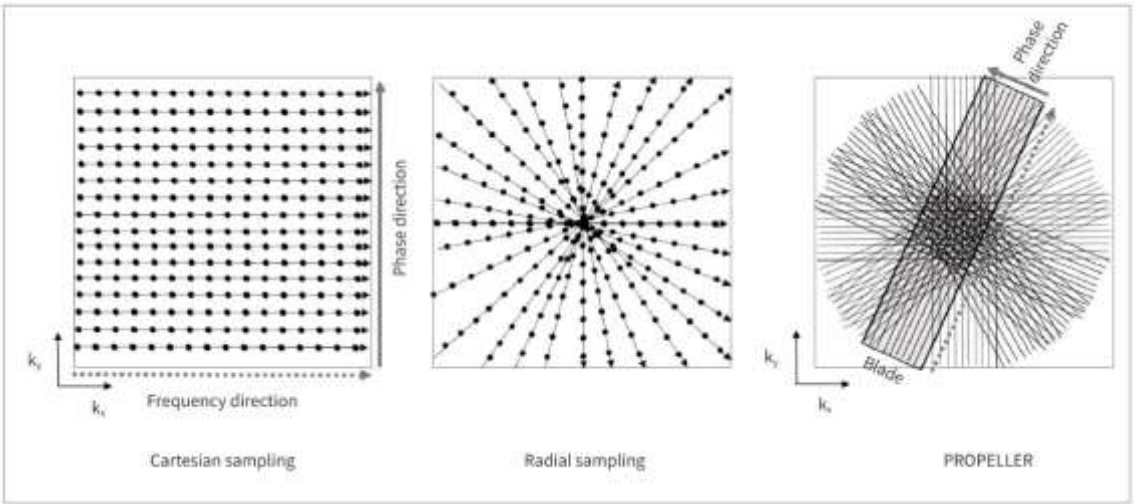


Figure 5: Image Representing K-space techniques for sampling. Cartesian sampling involves scanning k-space line-by-lines utilizing phase-encoded gradients & frequency-encoded gradients, accumulating samples from signal as

long as they reach the reverse edge. Cartesian is different from radial sampling, oversamples the k-space center & employs spokes overlapping, with all spokes contributing evenly to the image. The PROPELLER technique, a sort of radial sampling, captures samples in many parallel lines (blades) that spin progressively to cover the full k-space (62).

52 Hyperpolarised MRI an Alternate to Hydrogen Nucleus

Magnetic resonance imaging (MRI) can examine the lung without using ionizing radiation, making it useful for follow-up or dynamic time-resolved scans. MR pictures can be generated using a variety of nuclei other than the hydrogen nucleus. Noble gases, including Xenon (^{129}Xe) & Helium (^{3}He) are useful for visualizing the lungs & airways. In contrast to ^{3}He, ^{129}Xe has greater biological accessibility, & its special property (strong dissolvability for tissue & blood)) enables the separate examination of the gaseous and dissolved phases (67–69).

Hyperpolarised (HP) ^{3}He and ^{129}Xe were employed for physiological visualization, encompassing spin density, diffusion-weighted imaging, as well as gas exchange. (70–72). Global & regional patterns of lung ventilation can be determined by the HP ^{3}He and ^{129}Xe gases as well as detection and assessment of obstruction in the airway can be done in combination with hyperpolarised gas and magnetic resonance imaging. The approach of using ^{129}Xe gas becomes more readily available as the polariser technology advances & soon will be shifting to clinical use (71,72).

Whereas the initial hyperpolarized-gas (MRI) images were acquired with (HP) ^{129}Xe, & lung images were gained by using (HP) ^{129}Xe a few years later, hyperpolarised ^{3}He has been used in the great majority of human studies. It produces an extremely strong MR signal compared to ^{129}Xe because of its bigger nuclear magnetic moment & greater polarisation levels (> 30%). Additionally, there are no safety risks with breathed helium (73,74).

Whereas ^{3}He, ^{129}Xe are both abundant and affordable. Although the problem of ^{3}He attainability caused attempts to generate and examine hyperpolarized ^{129}Xe for human uses, it is vital to acknowledge that ^{129}Xe is more than just a lower-signal alternative to ^{3}He that we are compelled to employ owing to practical limitations. Particularly, the fairly high dissociation of xenon in human tissue plus magnificent responsiveness towards environment, leading to a vast variety of chemical shifts towards a solution. Therefore, ^{129}Xe is a clear potential alternate to ^{3}He as an ingested contrast material for MRI of lung (75,76), prove hyperpolarised ^{129}Xe especially appealing for investigating specific features of lung functioning, which includes gas exchange and uptake (77–80), when ^{129}Xe is inhaled it is also absorbed in the parenchyma of lung & blood, not just fills the air spaces of lung (fig 6). It is important to note that the chemical-shift difference is approx. 60 times between protons in water and fat than the dissolved & gas phase of ^{129}Xe in the lung. Diffusion of ^{129}Xe causes atoms to constantly swap with those in the dissolved compartments in the gas phase, this result in a formation of little pool of dissolved phase xenon in a dynamic equilibrium alongside xenon throughout airspaces (fig 7) (73,77,78,81).

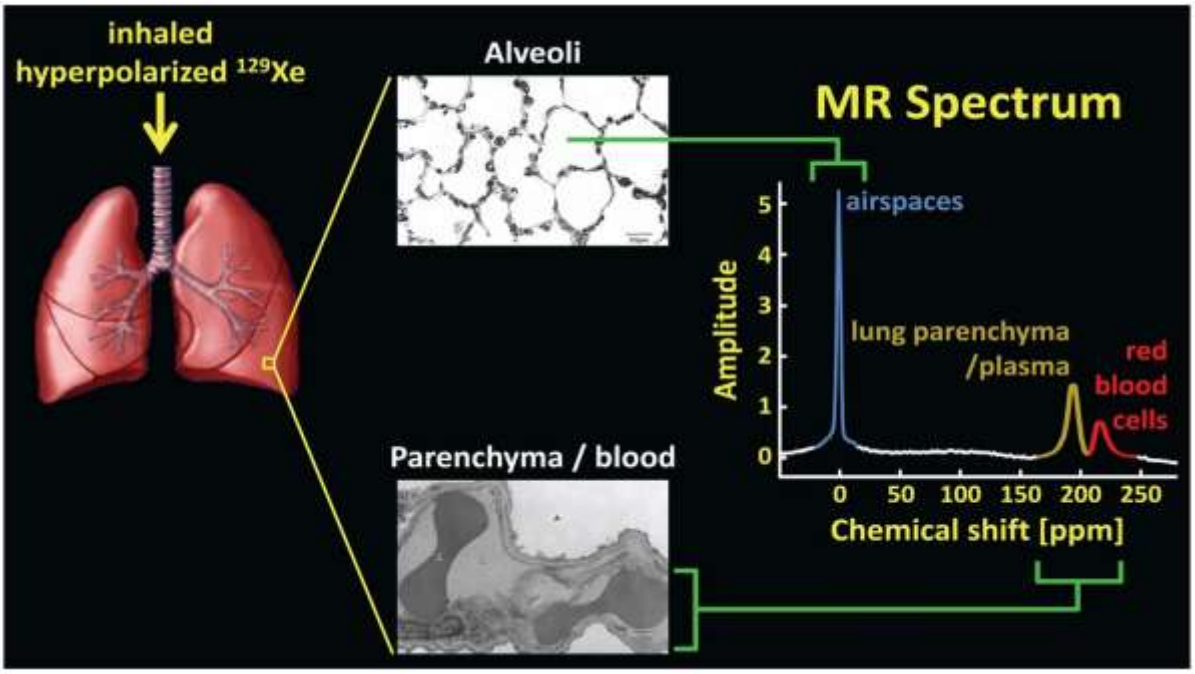


Figure 6: Showing the ^{129}Xe distribution in the lung not only in the spaces of air but also into the blood & parenchyma of the lung, due to a large chemical shift difference among blood/parenchyma & alveoli (74).

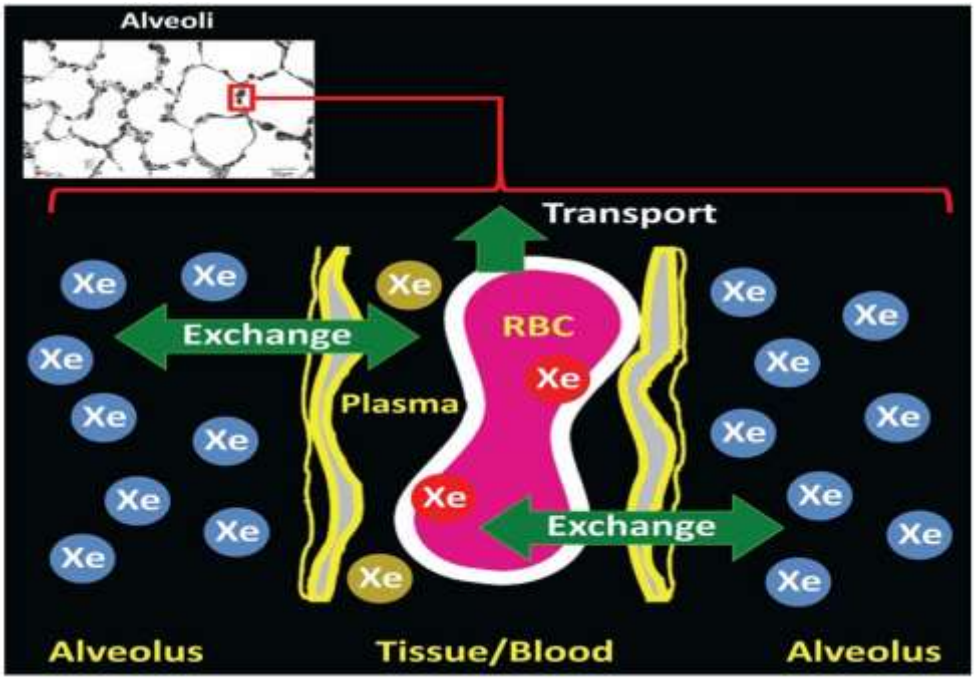


Figure 7: Representing the formation of dynamic equilibrium between xenon in blood/parenchyma & xenon in airspaces, that results in diffusion-driven exchange among (red & gold xenon atoms) that are dissolved phase compartment and (blue xenon atom) i.e. airspaces (74).

Fluorine-19 (^{19}F) gas ventilation has emerged as a cost-effective alternative to hyperpolarised techniques of MRI for assessing regional pulmonary ventilation. Because ^{129}Xe and ^{19}F gas approaches detect lung ventilation directly, they have become standard measurements of lung ventilation in MRI (67,82,83).

For different conditions like diseases related to airways, perfusion abnormalities & emphysema, MRI uses different methods to assess them. As for airway disease MRI uses ventilation defect percent and ventilated volume while perfusion abnormalities can be determined by gadolinium perfusion & xenon perfusion/diffusion & for emphysema apparent diffusion coefficient (ADC) is used (84).

Some difficult disorders, such as idiopathic pulmonary fibrosis (IPF), have been effectively treated by MRI which uses HP ^{129}Xe, due to the characteristics of the inert gas to depict its dispersion throughout the body including air gaps, red blood cells (RBC), & interstitial tissues (fig 8). The method of single-breath examination could end up being a suitable and non-invasive technology for characterization of pulmonary gas exchange failure in ILD (8,84–89).

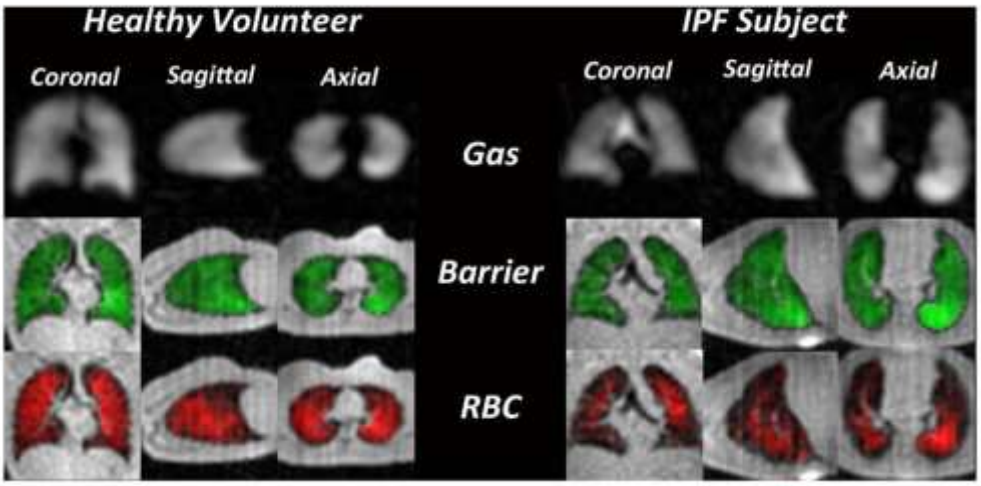


Figure 8: Images of a single breath of ^{129}Xe gas in (grayscale), tissue barrier in (green), &phases of red blood cells. The overall distribution of ^{129}Xe in healthy volunteers is relatively consistent across all 3 periods. The phase of gas

& barrier images have a fairly uniform intensity, whereas the images of RBC show widespread transfer of gas abnormalities in patients undergoing IPF (43)

5.3 Development of advanced MR sequences for imaging of the pulmonary region

The concepts of ultra-short echo time (UTE) and zero echo time (ZTE) sequences arose over two decades ago. Sequences made their comeback a few years ago as a result of advancements in the technology of scanners, the development of software, and sequence upgrading. Nowadays, various ZTE&UTE sequences have made their way to use clinically (90–95). These distinguished out of standard sequences of MRI by their exceptionally low echo times, making them appropriate for use in imaging of lungs. ZTE&UTE has lately been referred to as (game changers) for MRI of the lung (96–98).

Three-dimensional sequence (3D) i.e. UTE begins with a hard& non-selective pulse (With the availability of minimal phase SLR slab-selective pulse) lasting a few microseconds, and accompanied through center-out readout, which begins at the center of k-space and outward into a radial trajectory. Three-dimensional UTE is preferred over two-dimensional (2D) UTE because it delivers greater and isotropic spatial resolution, reduces motion artifacts, and completes chest coverage (59,99).

Zero echo time improves upon the ultra-short echo time carried out by using a reading gradient that can be switched on during excitation of RF to achieve lower echo periods. Characteristics include readout gradients and non-selective hard pulse excitation that remain constant. Because readout gradients do not require to be turned off soon after every readout, ZTE eventually culminates in faster and silent data gathering (59,60).

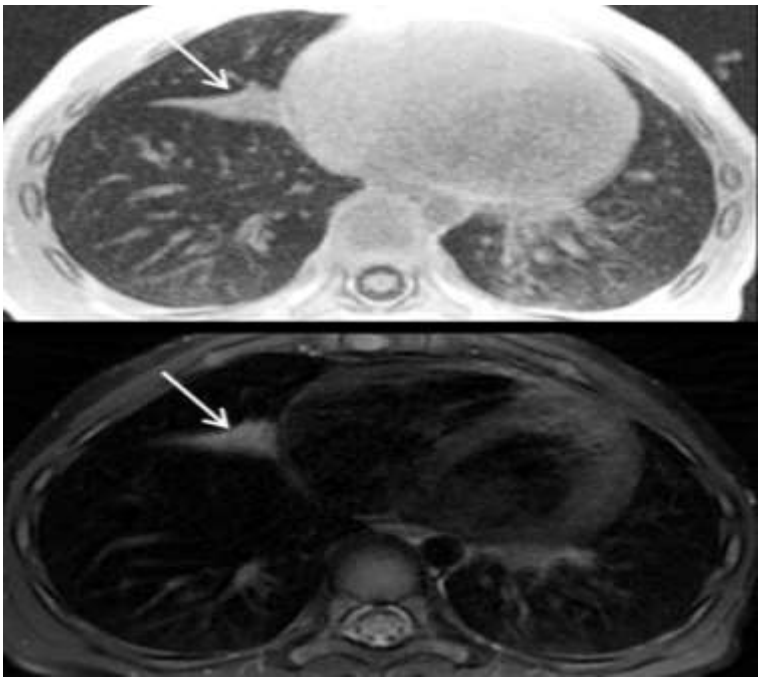


Figure 9: The image represents cystic fibrosis in a four-year-old female patient. Fat-saturated T2 weighted radial FSE at the bottom row & in the middle lobe consolidation arrows can be seen that are visible on UTE at the above row. UTE sequence permits greater visualization of peripheral lung markings (100)

6. ASSESSMENT OF VENTILATION & PERFUSION VIA DYNAMIC CHEST RADIOGRAPHY

For more than 50 years, researchers have worked to improve dynamic chest radiography (DCR) using traditional techniques of x-ray. Coinciding viewing of both the pair of lungs is possible due to advancement of having bigger field of view in dynamic flat-panel detector imaging. Visualisation and evaluation of heart motion, movement of the diaphragm & pulmonary ventilation & circulation is possible due to variation in pixel value of computer analysis (101).

Dynamic chest radiography is being approved for clinical usage in Japan. A typical modality includes a conventional system (X-ray), flat panel detector & workstation. The exposure of x-ray settings are as follows: tube voltage of 100 kVp, pulse duration of 1.6-3.2 ms, flame rate of 15 fps, and exposure time of 15 seconds. Furthermore, the pixel size was 0.4×0.4mm, with a total image area of 40×30cm. The dosage restriction for double conventional X-ray projections is 1.9 mGy, although the entrance surface dose in DCR is limited to 1.66 mGy (102,103). The typical approach involved obtaining dynamic pictures in three different phases as indicated in (Table 1).

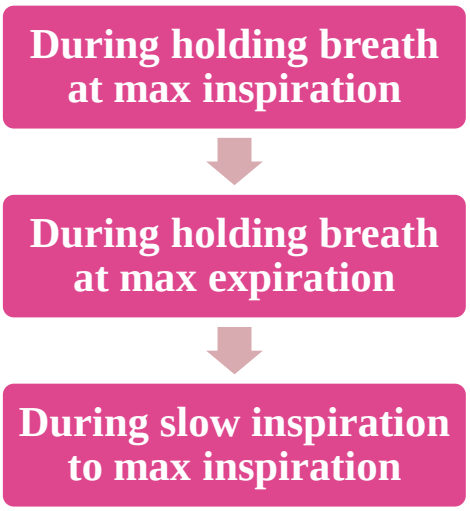


Table 1: Approach to obtaining dynamic pictures for different phases

Ventilation of the pulmonary region can be studied by identifying variations in the values of pixels throughout the phases of expiration & inspiration respectively, after filtering out circulatory noise. Without the use of contrast material, the blood flow of pulmonary can be determined by identifying tiny variations in the field of lung pixel values caused by the motion of the heart (cardiac motion) while holding the respiration. The method has been useful for analysing] tidal breathing. While pulmonary fluoroscopy is effective for manually analysing diaphragmatic movement, DCR analyses ventilation, perfusion, and lung structural motions, including the diaphragm automatically (104).

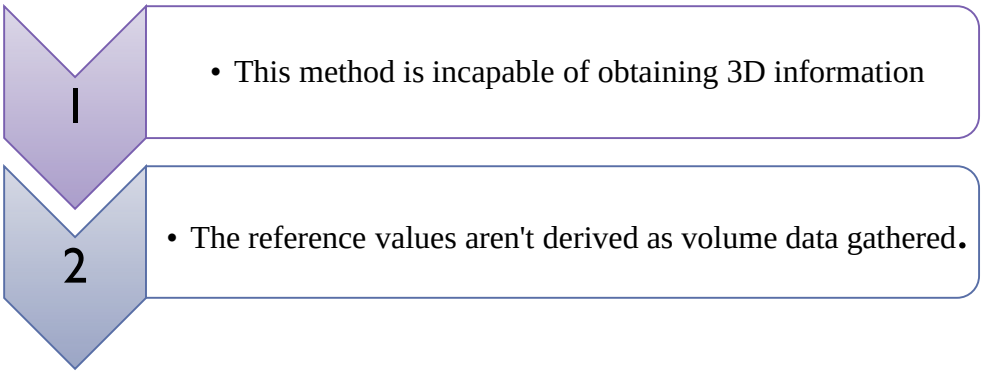
Research has shown that ventilation and perfusion abnormalities in a pig model were effectively observed using dynamic FPD imaging and DCR was equally efficient as ventilation & perfusion scans for spotting chronic thromboembolic pulmonary hypertension (105–107).

Research suggests that COPD patients during tidal breathing while standing have higher and faster motion of diaphragm compared to individuals that are healthy (108). COPD patients represents considerably smaller cranio-caudal gradients of max pixel value change percentage among tidal breathing compared to normal participants (109).

The preoperative assessment of lung carcinoma with pleural invasion can be evaluated by DCR (110). Dynamic chest radiography is expected to set off a common alternative to the radiography of the chest due to its ease of use, rapidity, cost-effectiveness, and minimal exposure to radiation. This technique has been & validated for use at the clinical level, such as implemented in the emergency room for screening of pulmonary embolism (111).

Apart from advantages, there are several limitations of this technique as mentioned in flowchart 1.

DCR is a valuable tool for monitoring treatment effects and postoperative changes. DCR allows physicians to visually witness the condition of patients, & computer-assisted diagnosis has promise for the future.



Flowchart 1: Limitations of dynamic chest radiography

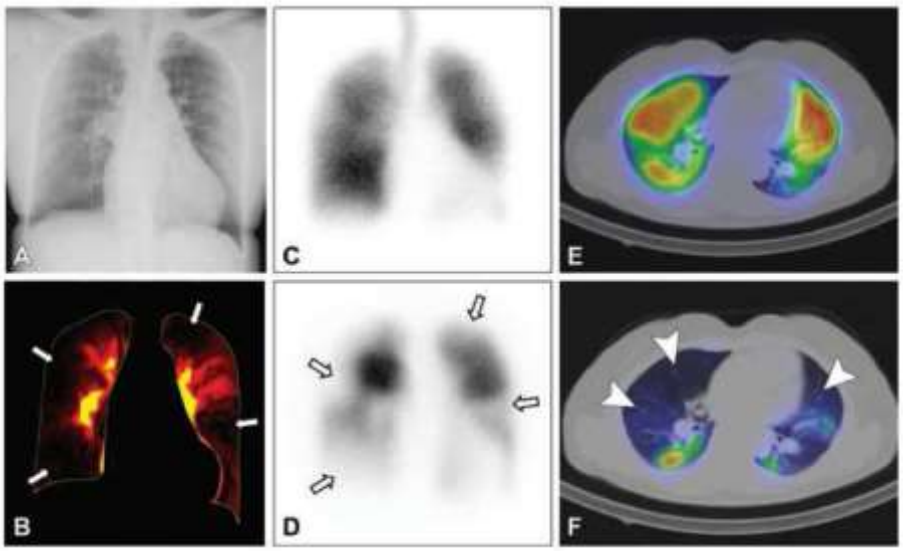


Figure 10: The image represents a patient with constant thromboembolic pulmonary hypertension in a woman 61 years older who was examined by ventilation-perfusion imaging and dynamic chest radiography. (A) Views of chest radiograph from anterior to posterior, (B) DCR-obtain dynamic perfusion images & lung perfusion map, (C) planar ventilation images of scintigraphy, (D) planar perfusion image of scintigraphy. A couple of wedge-shaped perfusion abnormalities (denoted by arrows in B & D) on both pair of lungs seemed to be found in perfusion map of the lung obtain by DCR (B), dynamic images of perfusion & planar perfusion scintigraphic image (D). Multiple segmental ventilation & perfusion differences (denoted by the arrow in F) appeared identified in (SPECT) ventilation images shown in (E) & perfusion shown in (F) (43).

7. SCINTIGRAPHY AND PET IMAGING

Pulmonary embolism is a curable condition caused by the formation of a thrombus in the lung blood vessels, most usually from the deep veins of the lower limb, disrupting blood flow toward the lungs. Imaging is used to diagnose pulmonary embolisms. The most popular and commonly used diagnostic modalities for diagnosing pulmonary embolism are ventilation & perfusion (V/Q scans). The pulmonary ventilation (V) & Perfusion (Q) scan is a nuclear test that employs a perfusion scan for determining the distribution of flowing blood while evaluation of airflow dispersion in the lungs is done by a ventilation scan. The V/Q scan is primarily used to diagnose lung clots known as pulmonary embolisms. These scans aid clinical decision-making by analyzing images that indicate ventilation and perfusion in various areas of the lungs using radioactive tracers (112).In traditional Scintigraphy, a radio contrast agent, such as technetium 99m-diethylenetriamine penta acetic acid (99mTc-DTPA) in the form of droplets & on the other hand gamma-emitting 99mTc-macro aggregated albumin (MAA) is injected to the patient intravenously to monitor perfusion & breathing. while the distribution throughout the pulmonary arteries & alveoli is done by the gamma camera. A high-probability PE scan reveals a couple of sub-segmental perfusion anomalies in the well-ventilated location (V/Q mismatch) (113,114).

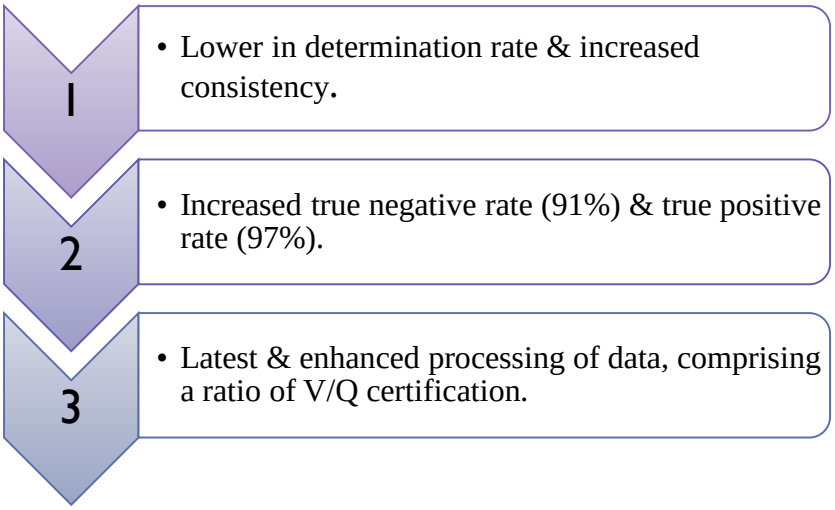
The acquisition of data begins when the patient is placed on the examination table & instructs for regular breathing at the time scans from various angles are performed by a technician. The process of examination is performed in two steps & can be completed simultaneously or consecutively. There are basically two phases: Phase 1 (Ventilation) & Phase 2 (Perfusion). During phase 1 radioactive technetium/ xenon is inhaled via a mouthpiece nebulizer for several minutes. Then images are taken from different angle by placing a gamma camera close to the patient. During phase 2 radioactive contrast technetium is injected via intra-venous route and images are captured. While V/Q uses distinctive pulmonary arterial segmental anatomy where each & every segment is perfused by a single end artery & every segment of bronchopulmonary contains its base towards the surface of the pleura. Traditionally, a thrombus that blocks the arteries in the pulmonary region will result in segmental; wedge-shaped lobar, or sub-segment abnormalities depending on the grade of obstruction. Various products, including radiolabelled aerosols 99mTc-DTPA & inert gases (81mKr, 133Xe), are employed in the ventilation phase via inhalation. During the perfusion phase 99mTc-labeled ultra-fine dispersion of technetium-labeled carbon is used intravenously (115,116)

Imaging protocols:

Various imaging procedures are used, including V/Q imaging with SPECT (V/Q) and, in exceptional instances, planar scintigraphy (V/Q) & occasionally only perfusion scanning is used.

7.1)Ventilation/ Perfusion & Single Positron Emission CT approaches of imaging

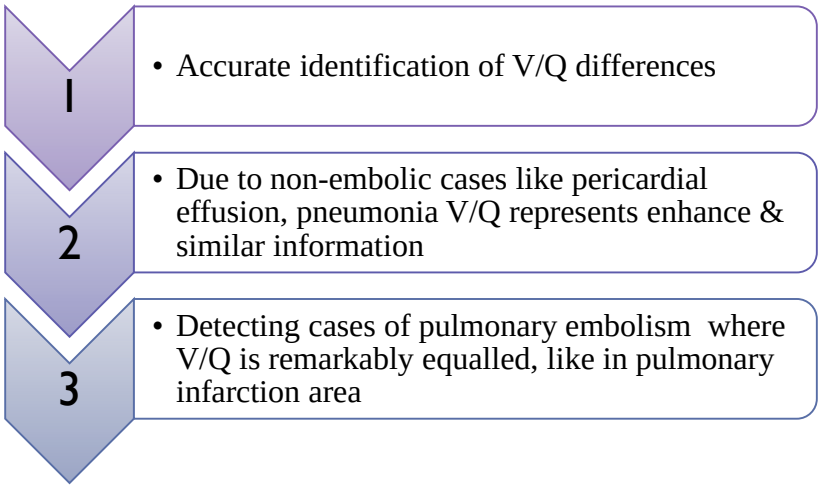
SPECT generates three-dimensional images by using multi-detector gamma cameras. SPECT demonstrated greater precision instead of the planar method (117). If computed tomography pulmonary angiogram (CTPA) contrast & exposure to radiation are inadvisable or absolutely necessary to avoid, the ventilation/perfusion in combination with SPECT is accounted for further diagnostic evaluation (118,119).



Flowchart 2: Benefits of V/Q & SPECT Technique

7.2) Integrating imaging techniques of computed tomography & SPECT

Extensive anatomical details can be obtained by combining a low-dose computed tomography & functional SPECT. The images of CT (excluding contrast) are often obtained following the perfusion scan (118). The primary disadvantage is exposure to radiation.



Flowchart 3: Advantages

8. ULTRASOUND

Lung ultrasonography (LUS) is commonly used for detecting abrupt respiratory insufficiency. Certainly, used in department of emergency for evaluating pneumothorax, pulmonary edema & acute respiratory distress syndrome (ARDS). Diagnosis of pneumonia can be done efficiently by this method of imaging (120).

LUS lung images exhibit various distinct characteristics (Figure 6). Pleural effusions are simply identifiable. Pleural motion is outlined as multiple regular lines movement that correspond to pleural sheets (lung sliding). The lines-A seen in LUS are horizontal hyper-echoic abnormalities caused due to the repetitive USG wave reflection among the probe & pleural line.

Reverberation reflection artifacts appear as vertically extending comet tails, known as the "B-line" when water & air coexist in the sub pleural secondary lobule

Tissue-like echogenicity may appear when there will be both consolidated lung tissue and collapsed tissue of the lung enter the pleura. Investigators have grouped the fusion of results into distinct indicators, proving the LUS precisely assesses illnesses like ARDS, cardiogenic pulmonary edema, & ILD (Interstitial Lung Disease) (121–124).

A non-invasive approach for measuring changes in thickness during respiration is lung ultrasonography of the diaphragm at its zone of apposition including rib cage. Diaphragmatic shortening is shown by the thickening of the diaphragm, while lack of thickening during inspiration implies paralysis of the diaphragm muscle. USG can differentiate among the non-functioning & functioning diaphragms, diagnose unilateral & bilateral paralysis of the diaphragm, and track diaphragm recovery that got paralyzed. It is effective in evaluating and diagnosing COPD & neuromuscular conditions (125–127).

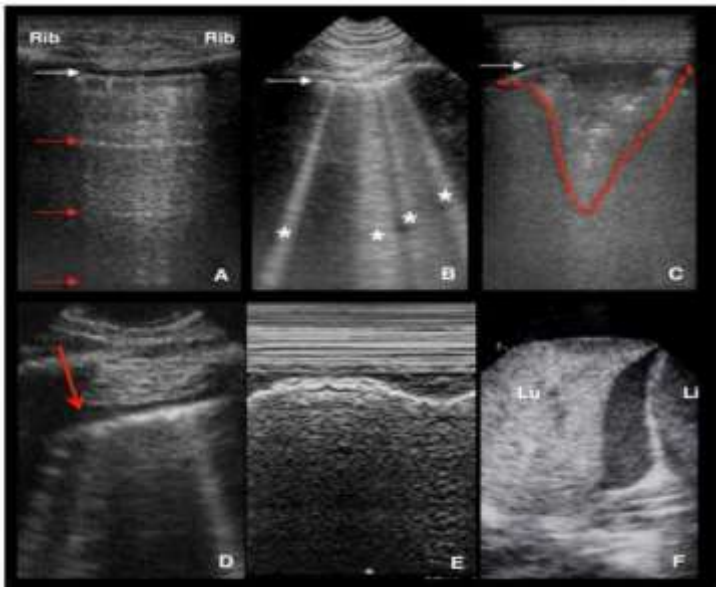


Figure 11: The image displays the essential manifestation of lung ultrasonography. (A) Arrow in white color denotes the pleural line among the ribs, whereas a horizontal reverberation artifact (denoted by red arrow) at regular intervals shows an elevated ratio of gas volume under the parietal pleura. (B) B lines are vertical artifacts originating from the pleural lining which move rhythmically along with lung sliding, are frequently hyper echoic & laser shaped, and eliminate lines A denoted in (white arrow). (C) Sub-pleural solidification denoted in (a dashed red line) is distinguished by irregular boundaries, sometimes known as the (shred sign). (D) Minute amount of pleural effusion is visible as a hypoechoic gap (red arrow) within the parietal and visceral pleura (43).`

9. ELECTRICAL IMPEDANCE TOMOGRAPHY (EIT) AND PATTERN LIGHT PROJECTION SYSTEM

The approach of electrical impedance tomography (EIT) is a non-hazardous imaging modality that is now extensively studied in the diagnosis & treatment of pulmonary region. Because of the superiority of simplicity in hardware, low operation cost, and free from radiation, it could be an excellent functional advanced method for lung imaging (128). The EIT measures surface voltages produced by a rotational injection of high-frequency & lower-strength alternating current among the electrodes surrounding the chest (129).

In recent decades, various new techniques of functional EIT have emerged, expanding the use of these features for investigating tissue impedance variations that are underlying. EIT imaging allows for direct observation of tissue impedances and fluctuations in tomography pictures. If there are more impedance changes in the tissues, the picture contrast will be higher. This is particularly true while examining the breathing process, where variations in the volume of air in the lung always cause considerable changes in chest impedance (130). EIT may provide cross-sectional images of respiratory function measurements in patients who are going through diseases like asthma (131), COPD (132), & cystic fibrosis (133), allowing for the study of regional and temporal variation. EIT signal fluctuations related to the heartbeat are caused due to regular changes in the diameters of blood vessels which are used to monitor lung perfusion. While prostacyclin-induced vasodilation (134) & hypoxic vasoconstriction (135) can be detected through these methods.

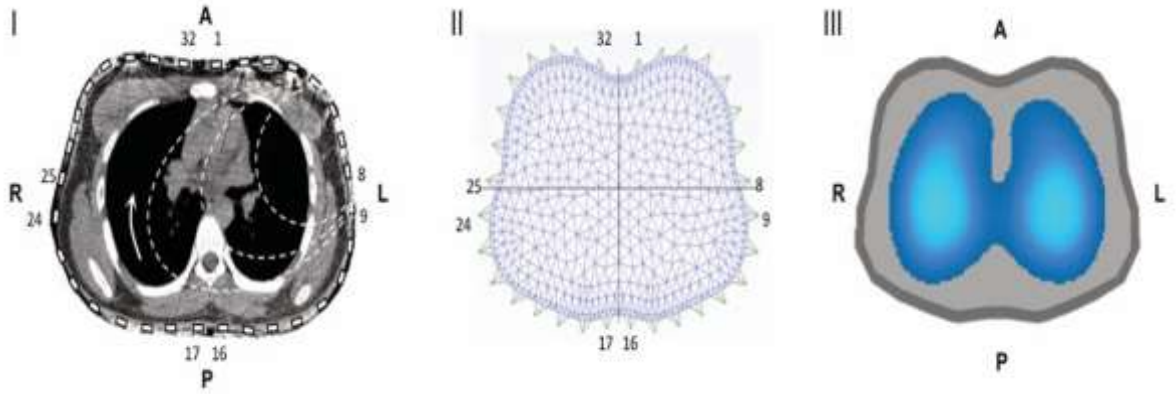


Figure 12: Images shown on this figure on the far left side (I) Depending on the resistance of every chest structure during the flow of current electric signals are dispersed. The middle (II) shows a mesh of electrical signals that showcase an even arrangement of electrical distribution. The activating current is delivered sequentially among sets of adjoining electrodes. The other electrode pairs monitor every injection of current voltages (U). On the right (III), the images created while ventilation using electrical impedance tomography enlightened 1800, with 32 electrodes (136).

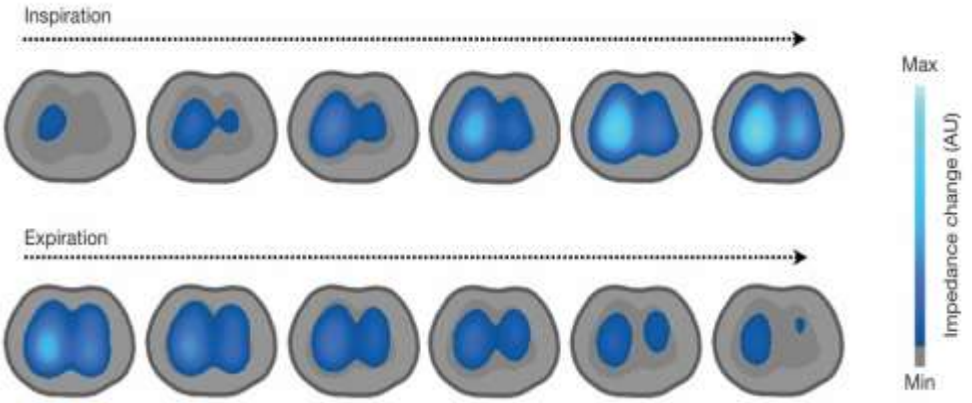


Figure 13: Inspiration as well as expiration dynamic images across one breathing cycle, acquired utilizing electrical impedance. Tomography enlightened 1800 (136).

A contactless respiratory assessment device combining a fiber-grafting (FG) vision sensor & technology based on a pattern light projector, as opposed to traditional systems that need sensors connected to body surfaces. The FG vision sensor device includes a projection system, two charge couple devices cameras located above the bed, with a computer for data interpretation. FG projector consists of a source of laser beam & an FG element (fig 14). The former is a diffraction grating made up of 2 superimposed sheets of glass fiber orthogonally arranged. A couple of brilliant spots are distributed throughout the surface of the confronting object. The FG projector projected around 800-1000 bright lights down the bed, while CCD_1 identified 200-300 specks that shifted with breathing. CCD_2 generates human body shape in real-time by examining the spot data (137,138).

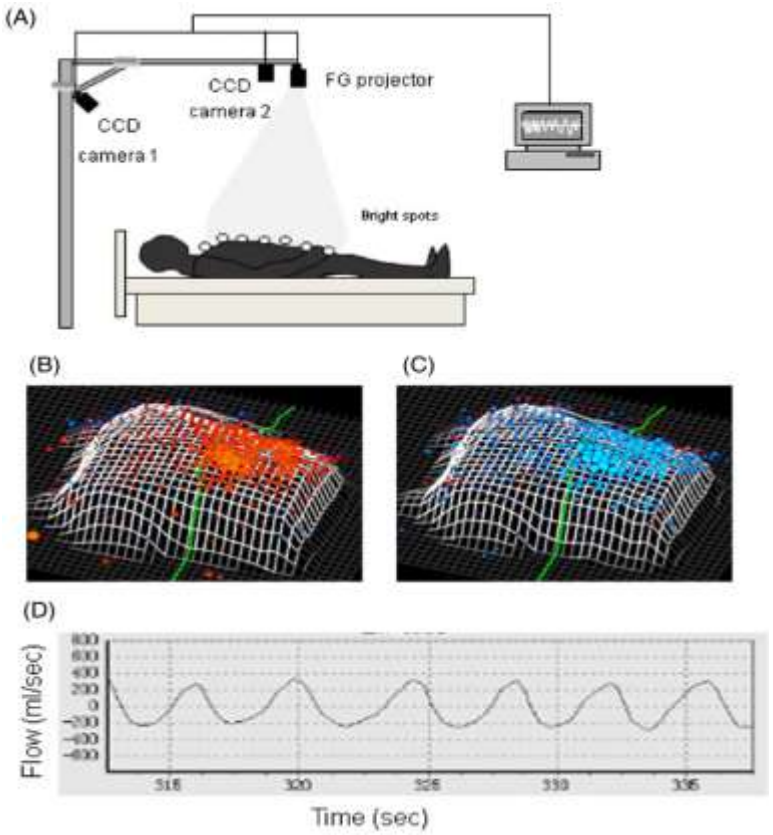


Figure 14: FG vision sensor. (A) The device layout includes an FG projection device, two CCD cameras, and a computer. (B), (C) A COPD patient's FG sensor shape and breathing motions are displayed on the monitor. The colored (B) & blue (C) Up and down motion are represented by spots, respectively, & the circle sizes reflect the rate at which volume changes. (D) A time-flow graph of a healthy individual obtained by FG sensor (137)

10. CONCLUSION

When imaging modalities like CT, MRI, dynamic chest radiography, Scintigraphy, PET, SPECT, EIT, and USG are combined with artificial intelligence and machine learning, it provides an advanced enhancement of pulmonary structure and function for patients with respiratory diseases. As CT-based imaging was able to predict the clinical outcomes of COPD patients and can evaluate the functional assessment of respiratory diseases by modern techniques like Jacobian determinant and parametric response mapping followed by Ultra-high-resolution CT, which made possible the imaging of silent zones that are represented as narrow airways relative to lung size and Dynamic CT allows the examination of emphysema, along with ventilation & perfusion in COPD patients with a single breath hold. Hyperpolarized and gas ventilation MRI has been developed to directly examine regional pulmonary ventilation as well as ZTE & UTE that are out of standard sequences of MRI with their exceptionally low echo times, making them appropriate in lung imaging. DCR is developed that provide a simultaneous view of both lungs with diaphragmatic movement, heart motion, and pulmonary circulation. Scintigraphy and PET are developed, which provide scans based on V/Q by administering radioactive tracers. LUS has been deployed to emergency rooms for evaluation of pulmonary edema, and EIT generates the images by electrodes applied on the chest region to assess pulmonary function.

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