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# High Resolution Computed Tomography and Chronic Obstructive Pulmonary Disease

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## 1. Introduction

Chronic obstructive pulmonary disease (COPD) is a preventable and treatable respiratory disease with some significant extrapulmonary effects that may contribute to the severity in individual patients. Its pulmonary components are characterized by airflow limitation that is not fully reversible. COPD is a leading cause of morbidity and mortality worldwide. The economic and social burdens due to it are substantial and anticipated to increase in the coming decades due to continued exposure to COPD risk factors and the changing age profile of the world's population. COPD mortality trends generally track several decades behind smoking trends. In US in 2000, more women than men died of COPD or its related complications.

COPD comprise of a heterogeneous group of disorders conventionally including emphysema, chronic bronchitis, peripheral airways disease and pulmonary vascular disease. It is a disease state that has seen significant changes in defining and excluding criteria over past 50 years. Spirometry, the most frequently used tool to diagnose COPD and to assess response to treatment in these patients, can provide only functional assessment. In contrast to spirometry, radiological imaging allows for regional assessment of the various compartments involved i.e. airways, parenchyma and vasculature. High-resolution computed tomography (HRCT) is recommended for the non-invasive and sensitive assessment of morphological changes in emphysema and has been shown to correlate well with pathology. With the advent of new imaging techniques like multi-detector row CT (MDCT), contrast-enhanced CT methods, spirometric controlled MDCT, use of Xenon gas to assess regional ventilation of the lungs, magnetic resonance imaging (MRI) of the lung developing its own arsenal like hyperpolarized He-3 MRI – new avenues are being opened up which are now increasingly supplemented with advanced and dedicated softwares.

## 2. Advantages of high resolution computed tomography

At present the diagnostic criteria recommended by the Global Strategy for the Diagnosis, Management and Prevention of Chronic Obstructive Lung Disease (GOLD guidelines) do not consider CT findings during initial diagnostic assessment (Pauwels & Buist 2001) and principally rely on spirometry. However, enough scientific literature suggests that HRCT is an important and indispensable tool for evaluation of COPD. Some of the uses of HRCT are described below in next sections.

### 2.1 Identifying causes of airway obstruction other than COPD

Chronic airflow obstruction may be caused by a wide variety of diseases like bronchiectasis, upper airway lesions, bronchiolar diseases, interstitial lung diseases etc that may often produce clinical symptoms inseparable those due to COPD. HRCT can clearly identify different causes of airflow obstruction. Kurashima et al (2005) showed in 516 consecutive patients whose postbronchodilator FEV1/FVC was less than 70%, HRCT was able to identify 12.7% of patients with pulmonary diseases other than COPD including sarcoidosis, diffuse panbronchiolitis and pneumoconiosis. The exact diagnosis of underlying pathology leading to air flow obstruction is essential in management and to predict response to treatment in these patients.

### 2.2 Identification of emphysema before appearance of clinical symptoms

HRCT can detect pulmonary emphysema even in asymptomatic smokers with normal lung functions. Recent GOLD guidelines have abolished stage 0 that included asymptomatic patients who were smokers and had normal lung functions; however, Sverzellati et al (2007) observed that 13/18 subjects with stage 0 had emphysema detected over HRCT scan. It reflects that HRCT is a sensitive tool to detect emphysema before it is manifesting clinically or with deranged pulmonary functions. Detection of early emphysema may be of enormous value to prevent its progression by smoking cessation and medical intervention (Morgan 1992).

### 2.3 Identifying and quantifying emphysema in patients with COPD

Emphysema, characterised by a parenchymal-predominant pathology in COPD and chronic bronchitis with an airway-predominant one are distinct phenotypes and might have evolved due to different responses to and pathogenesis related to smoking (Patel et al 2006). The emphysematous phenotype is conventionally associated with a more severe form of disease (Boschetto et al 2003, 2006). COPD patients with emphysema on HRCT have been observed to have higher BODE index (body mass index, airflow obstruction, dyspnoea, exercise performance) and a lower inspiratory capacity to total lung capacity ratio (IC/TLC) than those without emphysema. This suggests emphysematous patients have more extensive systemic involvements (Boschetto et al 2006). The ability to separate airway-predominant from parenchymal-predominant pathology in COPD may prove useful in applying specific therapies designed to prevent airway remodelling and parenchymal destruction (Grenier 2005).

HRCT often makes it possible to distinguish between different phenotypes of emphysema: smoking related phenotype, the centriacinar emphysema; and phenotype associated with α1-antitrypsin deficiency, panacinar emphysema. Moreover, HRCT can detect the coexistence of both panacinar and centriacinar emphysema in the same individual, as some patients with α1-antitrypsin deficiency may also be smokers (Copley et al 2002).

### 2.4 Detection of co-existing bronchiectasis

Presence of bronchiectasis in COPD patients on functional evaluation using spirometry is often not detected; this fact become appreciable when HRCT studies are done. One study observed that 29% of COPD patients who were having frequent exacerbations had bronchiectatic changes detected on HRCT (O'Brien et al 2000). Patel et al (2004) found that the extent of lower lobes bronchiectasis in these patients was related to colonization by the potential pathogens, increased inflammatory markers, and a longer time to symptom recovery after exacerbation.

The likely pathogenesis for typical structural abnormalities seen on HRCT include damaged muco-ciliary transport, localized or diffuse peripheral obliteration of the bronchial tree and lung tissue scarring – all these may be acting in concert in COPD.

### 2.5 Evaluation of large airways

Airway predominant pathology in COPD is significant and it is diagnosed conventionally based on clinical symptomatology of chronic or recurrent excess of mucus secretion in the bronchial tree (chronic was defined as occurring on most days of three months of a year, for at least two successive years), in whom other causes of chronic cough have been excluded (American thoracic society 1995). With the development of multidetector-row computed tomography (MDCT) understanding of the larger airway diseases has been improved dramatically. Volumetric thin-section CT scans are able to detect small pits or diverticulae along the inner surfaces of the large bronchi (Zompatori et al 2006). These pits are supposed to correspond to dilated bronchial gland ducts opening into the large airway lumen (Grenier et al 2004; Zompatori et al 2006).

### 2.6 Assessment of regional distribution of emphysema

HRCT scan can also provide details regarding regional distribution of emphysema. The role of distribution of emphysema on HRCT as a predictor of mortality is a hot topic. One study reported a greater proportion of emphysema in the lower lung versus the upper lung to be predictive of mortality; the authors speculated that lower-lobe emphysema may be either a marker of increased disease severity or, alternatively, a phenotypic or pathobiologic variant (Martinez et al 2006). Other studies explored the influence of the distribution pattern of emphysema on different lung function parameters. A higher percentage of emphysema in the core was associated with a more reduction in diffusion capacity (Aziz et al 2005). The contribution of emphysema at core to pulmonary dysfunction (with FEV1/ FVC %) may be larger than at periphery (Nakano et al 1999).

### 2.7 Essential for surgical interventions in COPD

Two surgical therapies, bullectomy and lung volume reduction surgery (LVRS), are sometimes recommended in COPD patients. A chest radiograph may suggest the presence of bullae, but accurate existence and extent of such lesions can only be assessed with chest CT scans (Martinez & Chang 2005). Similarly, the presence, extent, and distribution of emphysema can precisely be determined with a chest CT scan. The work over lung volume reduction surgery (LVRS) suggests more benefits in patients with upper lobe emphysema (Cooper et al 1995).
A chest CT scan is an important tool to determine patients who should not undergo LVRS (Group NETTR 2001). In NETT, LVRS was associated with a high risk of death (16% with LVRS compared with 0% in subjects treated medically) at 30 days in two types of subjects with emphysema: (1) those with FEV1 of less than or equal to 20% of predicted and non–upper lobe–predominant disease, and (2) subjects with FEV1 of less than or equal to 20% of predicted and a diffusing capacity less than or equal to 20% of predicted.

## 3. High resolution computed tomography: evolution with the time

During the last couple of decades, HRCT has been widely used to evaluate emphysematous and chronic bronchitis components of COPD. The initial work by Edinburg group was to

use computed tomography to diagnose emphysema in living patients (Gould et al 1988). Since then, HRCT has been widely established to detect and quantify COPD and its subtypes. Several workers have studied the correlation of semi-quantitative scoring of COPD by HRCT, pathology, clinical features and pulmonary function tests (Sanders et al 1988; Gupta et al 2008, 2009). HRCT indices of emphysema reflect lung anatomy and represent the best way to assess emphysema severity in life (Newell et al 2004). The introduction of multidetector-row CT (MDCT) scanners has provided powerful tools to evaluate changes in both small and large airways. In addition, dynamic imaging via MDCT allows the assessment of perfusion and ventilation in the lung parenchyma. Therefore, CT is able to precisely define the pathological process by providing accurate anatomic informations as well as functional data from the area of interest.
The parameters that have been extensively used by different workers to detect and differentiate various diseases grouped under COPD, and to quantify these diseases are described in following sections.

## 4. Measurements of lung density

The digital data provided by HRCT can be analyzed to detect the presence and severity of emphysema by several means. The measurement of lung density for quantifying emphysema may be done by **visual estimation** or **automated techniques**, both of which have their proponents (Desai et al 2006). These methods demonstrated good correlation with pathological assessment of emphysema severity (Muller et al 1988; Gevenois et al 1996). The extent of the lung density representing the disease can be visually graded according to a categorical scale. A potential drawback of visual estimation is inter-observer variation, although observer disagreement in scoring the extent of emphysema has been an insignificant factor in many of previous studies (Desai et al 2006). The potential interobserver variation is balanced by the speed and the simplicity of the technique.
The extent of emphysema can be determined by using a **threshold technique** for image segmentation. This is accompanied by setting of lower threshold for normal lung attenuation. The total area of volume of lung is calculated first using the lower threshold value and amount of emphysematous lung is determined by calculating the percentage of lung that is less than threshold value (Muller et al 1988). This technique is called as "**density mask method**". Routinely, –910 HU is taken as threshold value. In a study, authors compared CT lung densitometry in 20 COPD patients and in control subjects (Lamers et at al 1994). They found that percentage of pixels with attenuation less than –910 HU correlated well with visual emphysema score. In another study, HRCT scans were obtained with 1 cm intervals in 38 subjects (Gevenois et al 1996). The percentage areas occupied by attenuation values inferior to thresholds ranging from –900 HU to –970 HU were calculated. Emphysema was microscopically quantified in resected lung specimen. The strongest correlation was found for –950 HU and pulmonary function tests also correlated with emphysema measured by density mask method. However, other workers tried to correlate relative areas occupied by attenuation values lower than eight thresholds ranging from –900 to –970 HU with macroscopic emphysema and observed that a standard can not be recommended for the measurement of emphysema. Using precise morphometric evaluation of resected lung tissue, Bankier et al (1999) showed that observers, regardless of their experience, tend to overestimate the extent of emphysema on CT, whereas CT densitometry correlates better with the morphometric reference. The

density mask has been used to identify subgroups of patients who may show benefit from lung volume reduction surgery (Fishman et al 2003). The percentage of emphysema quantified by density mask is also predictive of survival in α1-antitrypsin–induced emphysema (Dawkins et al 2003).

Another objective way to measure emphysema on HRCT is assessment of **mean lung density** (Nowell 2002). CT density is expressed as a linear scale in HU (water = 0, air = –1000). In this range, lung density is a direct measure of physical density and is determined by the relative mix of air, blood and interstitial fluid in tissue. Emphysema will lead to decrease in mean lung density on CT. Several studies have assessed CT lung density in normal subjects. However, the range of normality remains to be standardized. In a study, authors assessed the progression of pulmonary emphysema in 23 patients by means of lung density (Zagiers et al 1996). Patients were scanned twice with a 1 year interval. Mean lung densities decreased within this duration and proved to be more sensitive than FEV1 and carbon monoxide diffusion.

The **image histogram curve** of CT lung density values can be obtained using softwares and measures of skewness can be looked at as another mean of detecting and assessing the presence of emphysema. Tail of high density value is produced by large vessels and airways and in emphysema, there is an increase in the numbers of low density pixels and the whole curve is shifted to the left (MacNee et al 1991). In a study, three groups of individuals, 20 with emphysema, 20 with chronic bronchitis and healthy individuals underwent CT and cut-off point in the histogram that defines the lowest 10th percentile of the histogram was derived (Lamers et al 1994). They observed that it is possible to classify lung disease using this parameter.

The softwares available in addtion with MDCT scanners make it possible to recognize and quantify emphysema faster than human evaluation; and it is now possible to apply techniques measuring lung density to volumetric data. The resolution achieved in thoracic HRCT allows the application of **high-precision 3D image analytic tools** to CT data (Kuhnigk et al 2005). The analyses allow a convenient regional assessment of CT parameters including total volume, mean density, pixel index, and emphysema type (Kuhnigk et al 2005).

A density-masking approach alone is not sufficient to accurately distinguish between normal and diseased lung, especially in the case of early or mixed pathologic processes (Uppaluri et al 1997, 1999; Hoffman et al 2006). Further, CT densitometry is known to be influenced by several factors (eg, age, weight, beam hardening from adjacent ribs etc.) and calibration must be performed in order to obtain reliable densitometry. Neither visual nor pure densitometric approaches to CT quantification of emphysema are, therefore, perfect.

In addition to assessment of percentage of voxels below a certain threshold, more sophisticated analytic softwares may analyse the CT scan data, contiguous emphysematous lesions can be clustered to obtain the volumes for small-sized, medium-sized, and large-sized emphysematous areas (**cluster distribution**) (Blechschmidt et al 2001; Zaporozhan et al 2005). A serial assessment of cluster distribution is useful in revealing the pattern of progression of emphysema. Uppaluri et al (1997, 1999) examined multiple features of the CT images and X-ray attenuation values to describe the lung and developed the **Adaptive Multiple-Feature Method** (AMFM), which can assess up to 22 independent textural features from HRCT scans to classify a tissue pattern. This is found to be useful to distinguish smokers from non-smokers in the absence of other disease (Hoffman et al 2006).

## 5. Mosaic attenuation pattern and air trapping

Abnormalities on HRCT that reflect small airways disease can be broadly categorized into indirect and direct signs: widespread scarring and obliteration of the bronchioles results in the indirect sign of patchy density differences of the lung parenchyma, representing areas of under-ventilated and under-perfused lung (**mosaic attenuation pattern**). The considerable thickening of the small airways walls by inflammatory infiltrate and/or luminal and surrounding exudate render the affected **small airways directly visible** (Hansell 2001). Air trapping or hyperinflation is a common manifestation of COPD (Stern & Frank 1994). Persistent aeration caused by collateral pathways, or hyperaeration from trapped air, produces the mosaic attenuation pattern which is characterized by nonhomogenous lung density, i.e. areas that remain relatively lucent interspersed with areas of normal higher lung density. The air trapping and mosaic attenuation pattern is more pronounced, on scans obtained at end-exhalation instead of the more conventional end-inspiration technique (Arakawa & Webb 1998). In a recent study, it was found that mosaic attenuation pattern in addition to other HRCT features is helpful in distinguishing different entities grouped under COPD (Copley et al 2002).

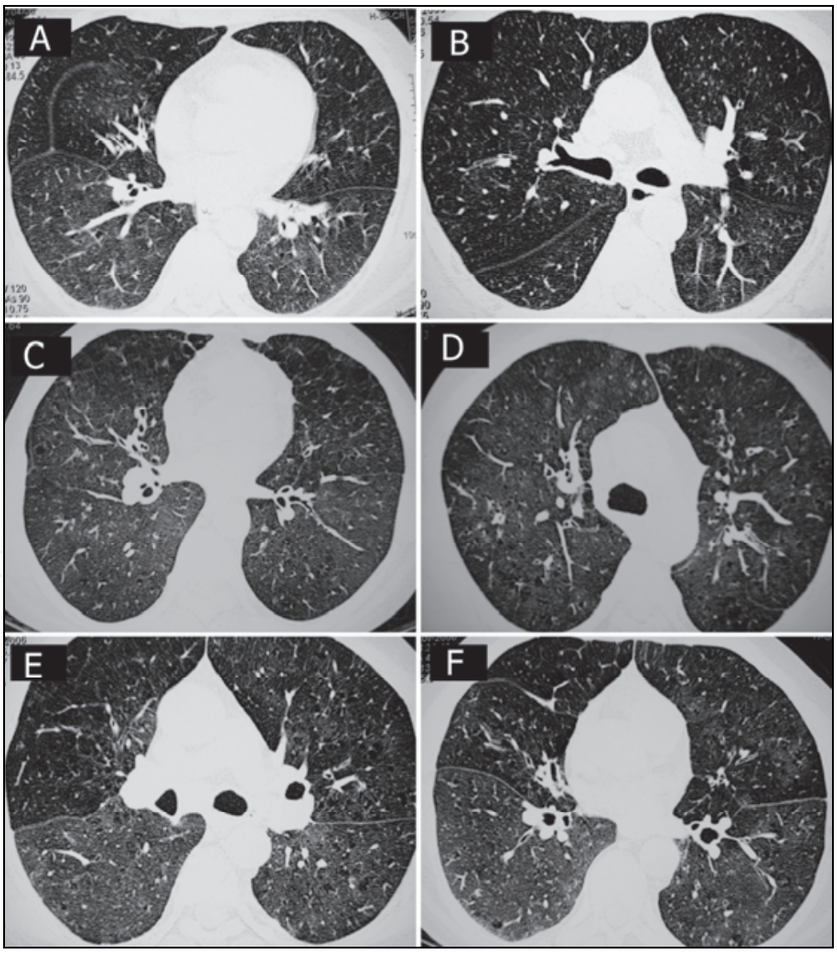


Fig. 1. HRCT scans showing non-homogenous lung density – a cardinal feature of mosaic attenuation pattern (A-F) observed on HRCT scan obtained from different COPD patients.

In our studies (Gupta et al 2008, 2009) including 40 COPD patients who were diagnosed based on GOLD criteria and who were evaluted for HRCT characteristics, 16/40 patients had classic mosaic attenuation pattern; the HRCT scans were undertaken during full inspiration. Some of these are shown in figure 1 (A to F).

## 6. Directly visible small airways

Several pathological studies have shown that the major site of airway obstruction in COPD is in airways with internal diameter lesser than 2 mm. The 2 mm airways are located between the fourth and the 14th generation of the tracheobronchial tree. These airways are not visible on HRCT scan in normal subjects. However, considerable thickening of the bronchiolar walls by inflammatory infiltrate and/or luminal and surrounding exudates render them directly visible (Hansell 2001). These diseased airways are visible on HRCT as dilated, air-filled, branching, tubular or ring-like structures in the lung periphery by wall thickening and dilation. When the airways are obliterated by submucosal or peribronchial fibrosis, nodular, linear, or branching peripheral opacities may be seen (Teel et al 1996). In our study, 36 out of 40 COPD patients showed directly visible small airways (figure 2).

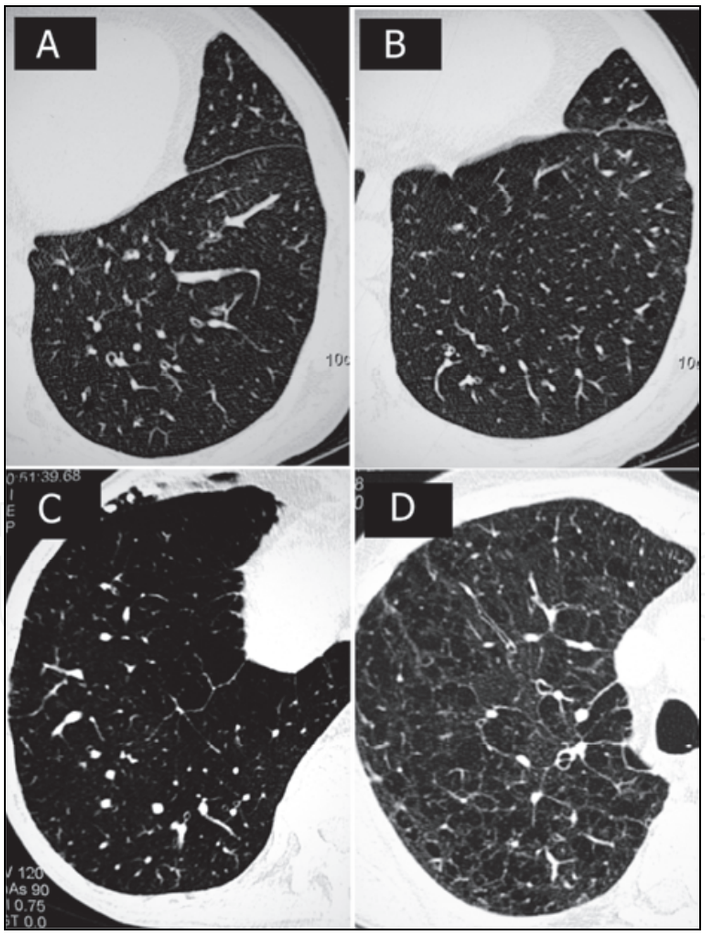


Fig. 2. HRCT axial scans showing directly visible small airways as (A-C) air filled ring like structures and (D) air filled branching tubular structures.

## 7. Measurements of airway wall thickness

It has been observed that the size of the large and intermediate airways reflect airway dimensions in the smaller airways (Nakano et al 2005). Due to the interobserver disagreement in the visual interpretation of bronchial wall thickness on CT scans (Muller and Coxson 2002), there has been considerable interest in the development of objective measurements of airway wall dimensions. The most frequently reported method for measuring the airway lumen and wall areas relies on the **"full-width-at-half-maximum" (or "half-max") technique**, in which the inner and outer airway wall boundaries are defined as the point corresponding to the half maximal intensity of the airway wall voxels (Nakano et al 2000; de Jong et al 2005). Using the half-max method, Nakano et al (2000) showed that an increased thickness of the apical right upper lobe bronchus over HRCT correlated with the severity of airflow obstruction in COPD patients. However, the measurements of airway lumen and wall area depends on the lung volume and angle between the airway central axis and the plane of section (Grenier et al 2004).

In 42 COPD patients, bronchi with external diameter of greater than 2 mm and maximum to minimum diameter ratio less than 1.5 were selected (Orlandi et al 2005). Thickness to diameter ratio (TDR) and the percentage wall area (PWA) of these bronchi were computed. For each patient, mean TDR and mean PWA were calculated. The combination of PWA, TDR and PWA normalized to body weight correlated significantly ($P < 0.05$) with FEV1/SVC ratio and DLco in patients with chronic bronchitis but not in patients without chronic bronchitis.

In another study, thickness to diameter ratio (TDR), and percentage of wall area (WA%) were calculated on HRCT in 4 groups of patients : group O - healthy non smokers, group I - healthy current smokers, group II - patients with moderate COPD and group III - those with severe COPD as per GOLD classification (Deveci et al 2004). Both groups II and III had higher T/D ratio and WA% than group I and group I had higher values than group O. Airway wall thickening was found to be inversely correlated with FEV1 and positively related to the quantum of smoking.

## 8. Low attenuation areas of emphysema

HRCT is a reliable tool for demonstrating even subtle changes in secondary pulmonary lobules. Low attenuation areas of emphysema are distinctly visible on HRCT scan. These focal areas of decreased attenuation present differently in different types of emphysema (Nowell 2002).

**Centriacinar emphysema** is the commonest type of pulmonary emphysema and is characterized by an enlargement of the centriacinar airspace, with the effect mainly occurring in proximal respiratory bronchioles, leaving normal distal alveolar ducts and sacs. In centriacinar emphysema, focal areas of decreased attenuation have no discernable wall and usually have a focal arteriole at or near the centre of lesion (Figure 3 A-F). Centriacinar abnormalities always have a distance of about 2.5 mm from the perilobular structure, including interlobular septum, pleura and large pulmonary vessels. Cigarette smoking and dust inhalation are the most important risk factors for the development of centriacinar emphysema. The disease is usually distributed to the upper lobe or the superior segment of the lower lobe. The inner zone is more severely affected than the outer zone, probably due

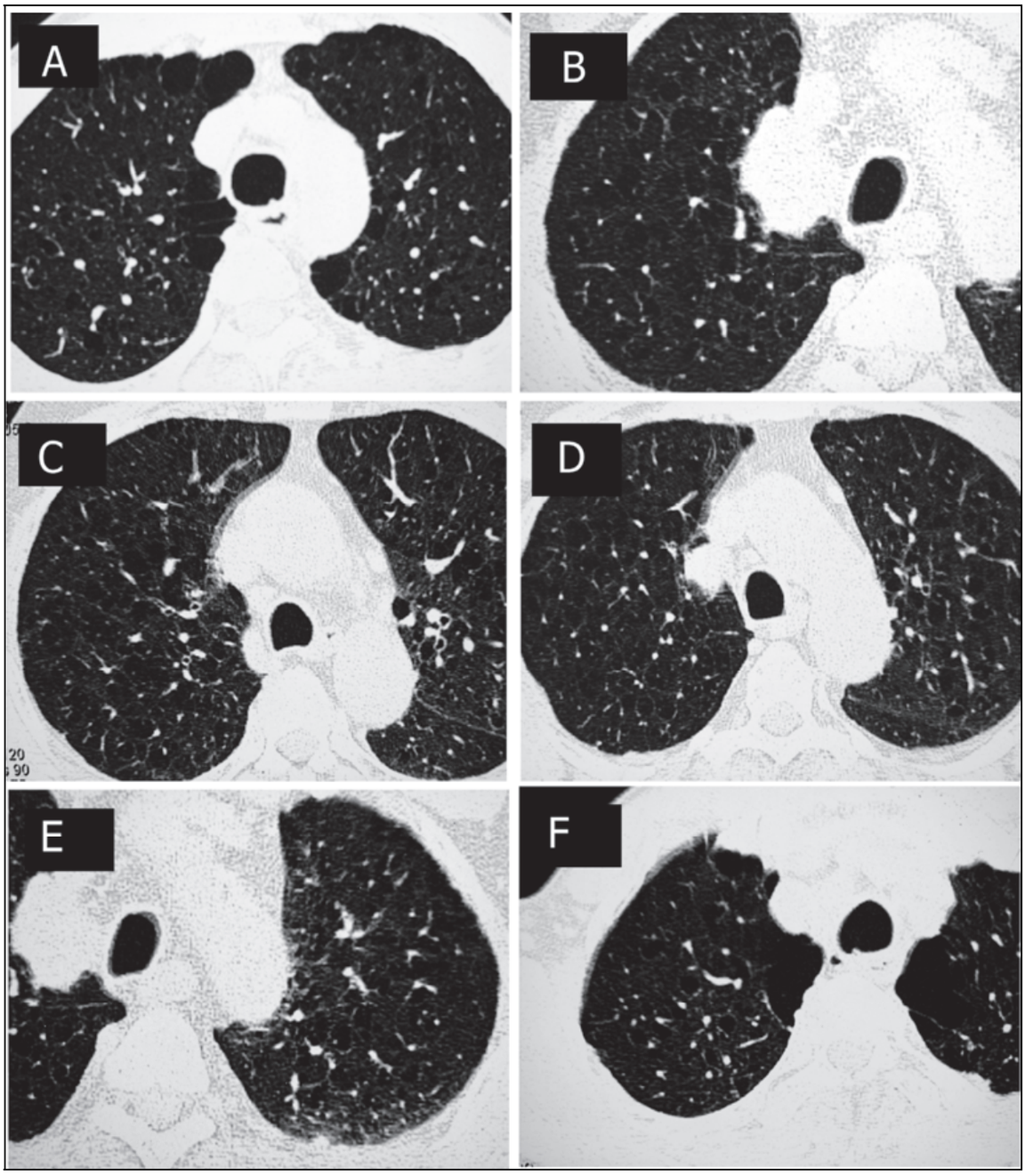


Fig. 3. HRCT scans in patients with centriacinar emphysema showing multiple, round lucent regions of various sizes surrounded by normal parenchyma (A-F).

to zonal differences in respiratory kinetics and lymph flow. HRCT in early centriacinar emphysema shows evenly distributed centrilobular tiny areas of low attenuation with ill-defined borders; with enlargement of the dilated airspace, the surrounding lung parenchyma is compressed and a clear border may be observed between the emphysematous area and normal lung.

**Panacinar emphysema** is characterized by a uniform dilatation of the air space from the respiratory bronchioles to the alveoli, leading to evenly distributed emphysematous changes within secondary lobules. Panacinar emphysema is characterized by large areas of decreased lung density or decreased attenuation on CT with poorly defined margins; the caliber of the vessels in the involved area is decreased due to overinflation of the air space [Figure 4 (A-D)]. Alpha 1-antitrypsin deficiency is thought to be a major cause of panacinar emphysema. Other rare etiologies, including Swyer-James syndrome and ritalin abuse, have been reported. The characteristics that distinguish panacinar emphysema from centriacinar emphysema are as follows: the disease is dominant in the lower lung field, the degree of lung inflation is greater than that in centriacinar emphysema; there is a tendency for the airway to be narrowed; and bullous formation is less frequently observed compared to centriacinar emphysema.

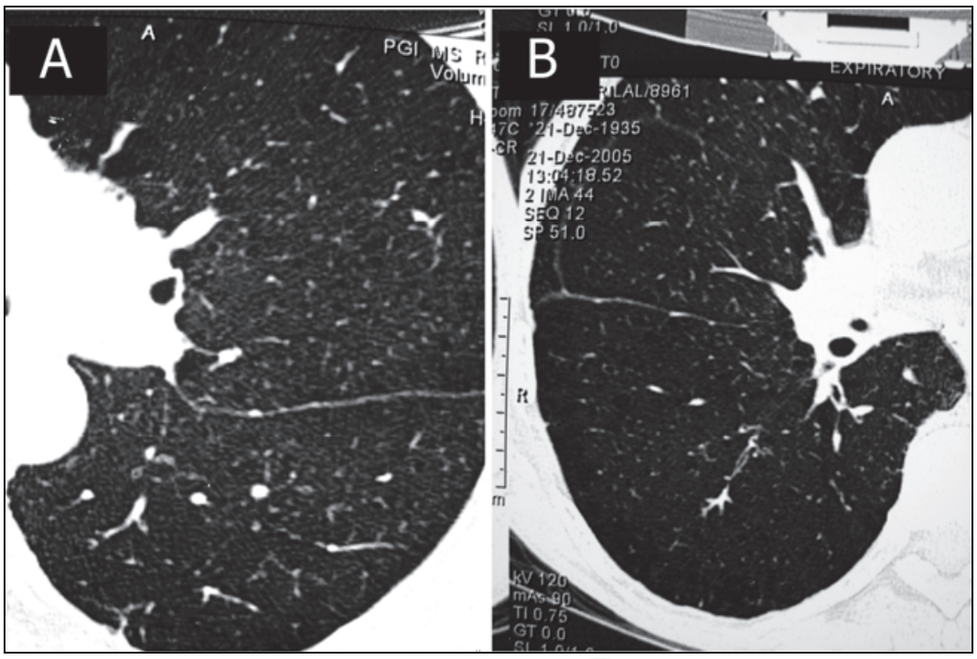


Fig. 4. (A-B): Panacinar emphysema: HRCT scans showing diffuse low attenuation lung parenchyma – typical of panacinar emphysema

**Distal acinar emphysema** is characterized by focal areas of subpleural emphysema. Distal acinar or paraseptal emphysema is characterized by an enlarged airspace at the periphery of acini. The lesion is usually limited in extent, occurs most commonly along the dorsal surface of the upper lung. The patients are usually asymptomatic, but distal acinar emphysema is considered to be a cause of pneumothorax in young adults.

The subtypes of emphysema can usually be determined in mild or moderate cases, but classification into anatomic subtypes becomes more difficult by HRCT and pathological examinations as emphysema becomes more severe, with even highly trained and experienced pathologists sometimes disagreeing on the classification. Centriacinar and panacinar emphysema may coexist in the same patient; for example, with centriacinar emphysema in the upper lobe and panacinar emphysema in the lower lobe.

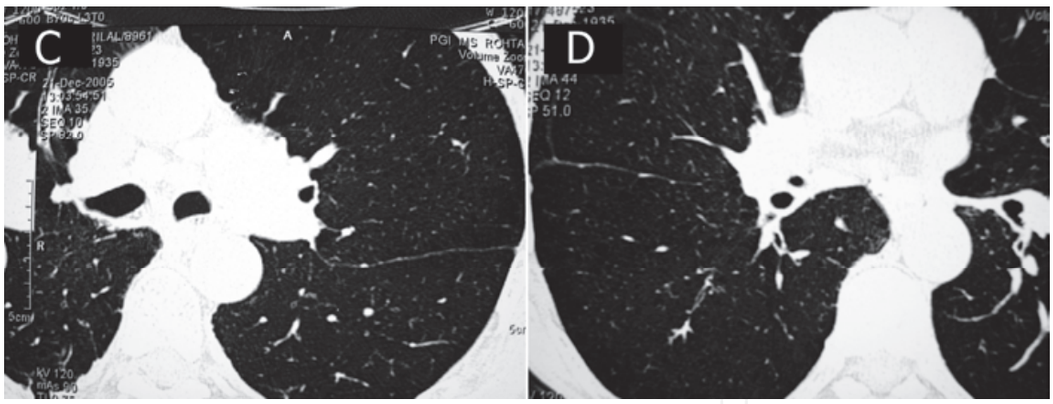


Fig. 4. (C-D): Some more HRCT scans showing panacinar emphysema

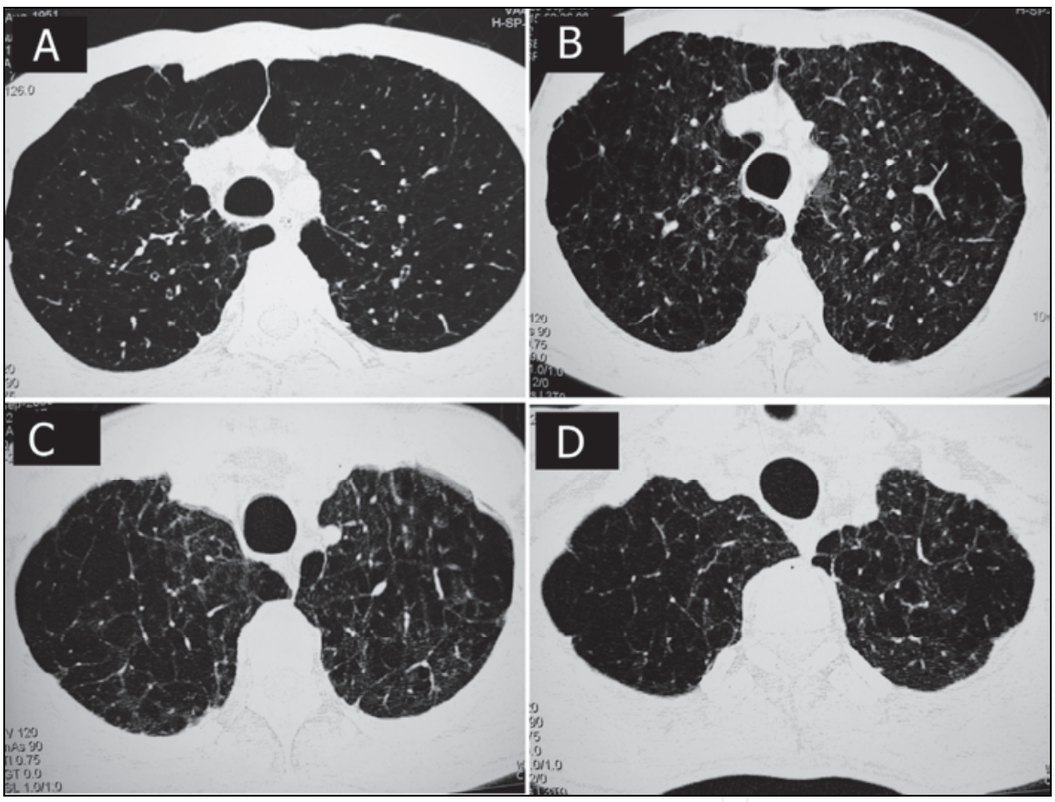


Fig. 5. (A-D): HRCT scans showing small subpleural areas of hyperlucency – characteristic of paraseptal emphysema.

Studies have been done to assess the accuracy of CT in diagnosis of emphysema by visual scoring of low attenuation areas. In a study, CT thorax was performed on 32 patients scheduled for elective thoracotomies for suspected lung tumours (Bergin et al 1986). Each slice was assessed and graded depending upon the percentage area showing emphysematous areas. Similarly, emphysema was graded on the resected lung specimens. It was found that compared to pulmonary function tests, CT was a better predictor of assessing the presence and severity of emphysema.

A retrospective study used HRCT scans for scoring the severity of emphysema (Klein et al 1992). Each of the six lung sections was evaluated and extent of emphysema multiplied by the severity was summed for the six sections. Concomitant chest radiographs and pulmonary function tests were reviewed. The severity of emphysema on HRCT correlated inversely with single breath carbon monoxide diffusion capacity. **HRCT allowed detection of emphysema in symptomatic patients when chest radiographs and pulmonary function tests were non-diagnostic.**

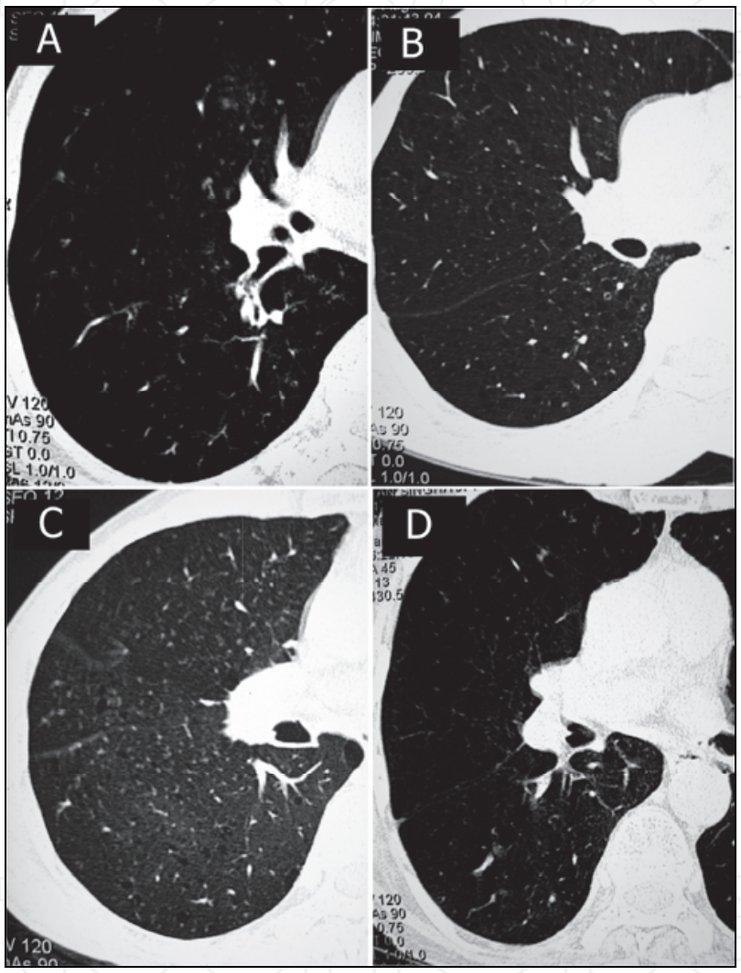


Fig. 6. (A-D) : HRCT scans of different COPD patients showing vascular attenuation characterized by thinning of pulmonary vessels at the peripheral lung field along with reduction in their number.

## 9. Vascular attenuation and vascular distortion

On HRCT of emphysema patients, low attenuation areas are frequently accompanied with vascular attenuation and distortion (Norwell 2002). **Vascular attenuation** is defined as thinning of pulmonary vessels and reduction in their number [figure 6 (A-D)]. **Vascular distortion** is increased branching angles, excessive straightening or bowing of vessels. [figure 7 (A-D)].

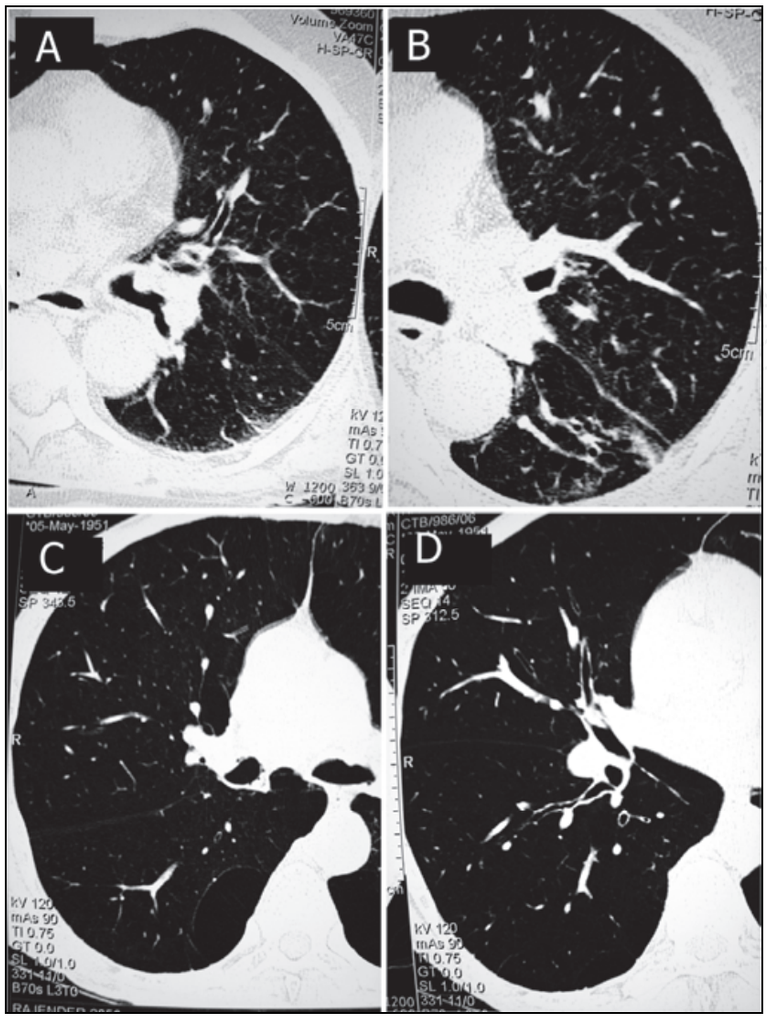


Fig. 7. (A-D): HRCT axial scans from COPD patients showing vascular distortion characterized by increased branching angles and excessive straightening of pulmonary vessels.

In a study, two radiologists and one chest physician assessed for destructive changes of emphysema manifested by low attenuation areas and disruption of vascular pattern (Kuwano et al 1990). Each slice was individually assessed using a modification of the **picture-grading system** of Thurlback (1994). CT scores correlated significantly with the pathological scores and it was concluded that HRCT can help to identify the presence and grading of mild emphysema. Other studies have found that vascular disruption in addition to areas of low attenuation is helpful in assessing and grading emphysema (Bergin et al 1986).

## 10. Saber-sheath trachea and tracheal index

In cross-section, the resting trachea is roughly horse-shoe shaped, with the open end of the cartilage rings closed by a compliant posterior sheath. In COPD patients, the coronal diameter is reduced and the saggital diameter correspondingly increased, a condition called **saber-sheath trachea** [Figure 8 (A-D)] . **Tracheal index** is a ratio of the coronal to the saggital length, measured 1 cm above the aortic arch.

In a study, it was found that patients with COPD had a reduced tracheal index. Saber-sheath trachea (tracheal index < 2/3) was observed to be a specific radiographic diagnostic parameter for the diagnosis of COPD (specificity, 92.9%), although sensitivity (39.1%) was low (Tsao et al 1994).

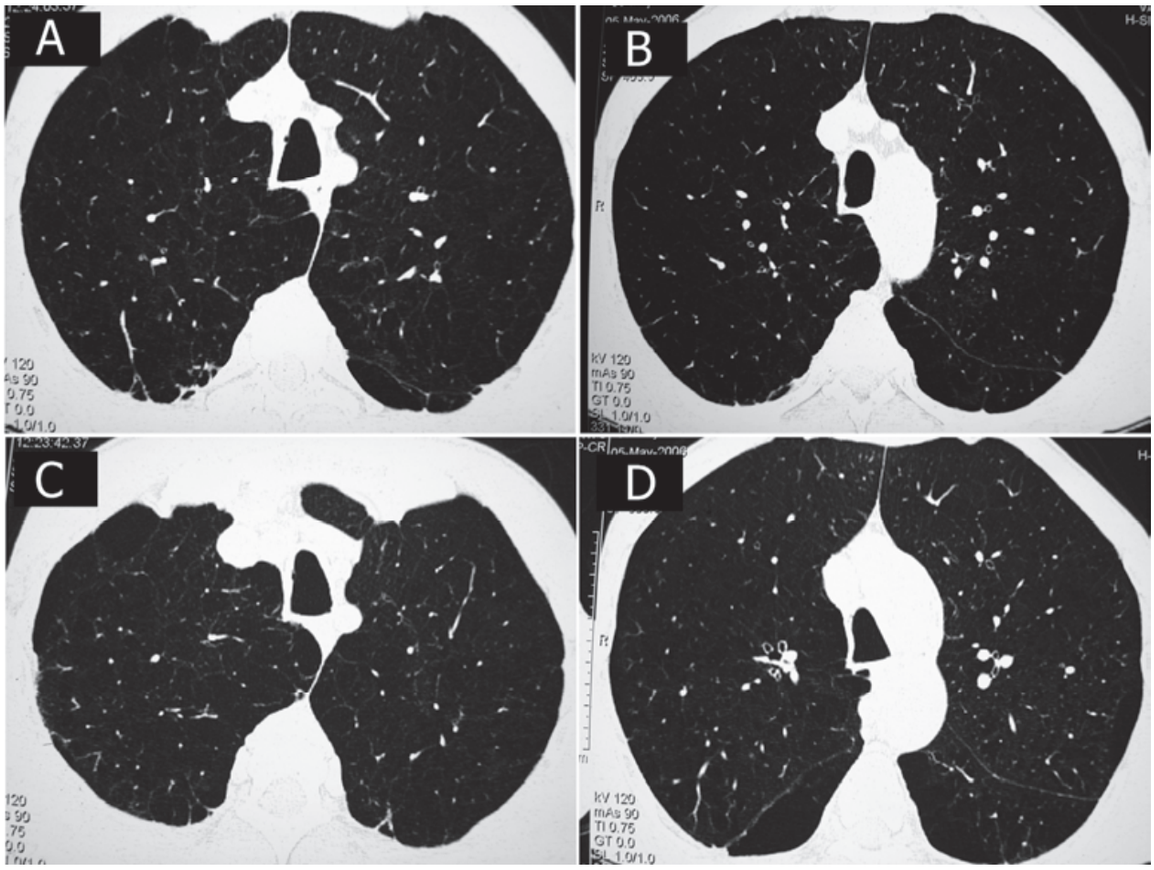


Fig. 8. (A-D): Saber sheath trachea over CT scans in COPD patients

In another study (Trigaux et al 1994), 20 patients with saber-sheath trachea were compared with 20 controls without saber-sheath trachea by measuring standard HRCT indices of COPD and functional tests including FEV1, DLco and FRC. Tracheal index was significantly correlated with the FRC values and it was concluded that saber-sheath trachea is basically a sign of hyperinflation in COPD pateints. Similarly, in a different study (Arakawa 1998), reduced tracheal index and other signs of hyperinflation of thoracic cage on CT were found to correlate significantly with pulmonary functions of chronic airway obstruction.

## 11. Sterno-aortic distance and mediastinal anterior junctional line

In retrosternal region, right and left lung with their corresponding pleural layers approach each other so closely that the area of contrast form a linear density. When present, the line is 1 to 2 mm wide and formed by two pleural layers on each side of a narrow zone of mediastinal connective tissue. This line is called **anterior junctional line** (AJL) [figure 9 (A-D)].

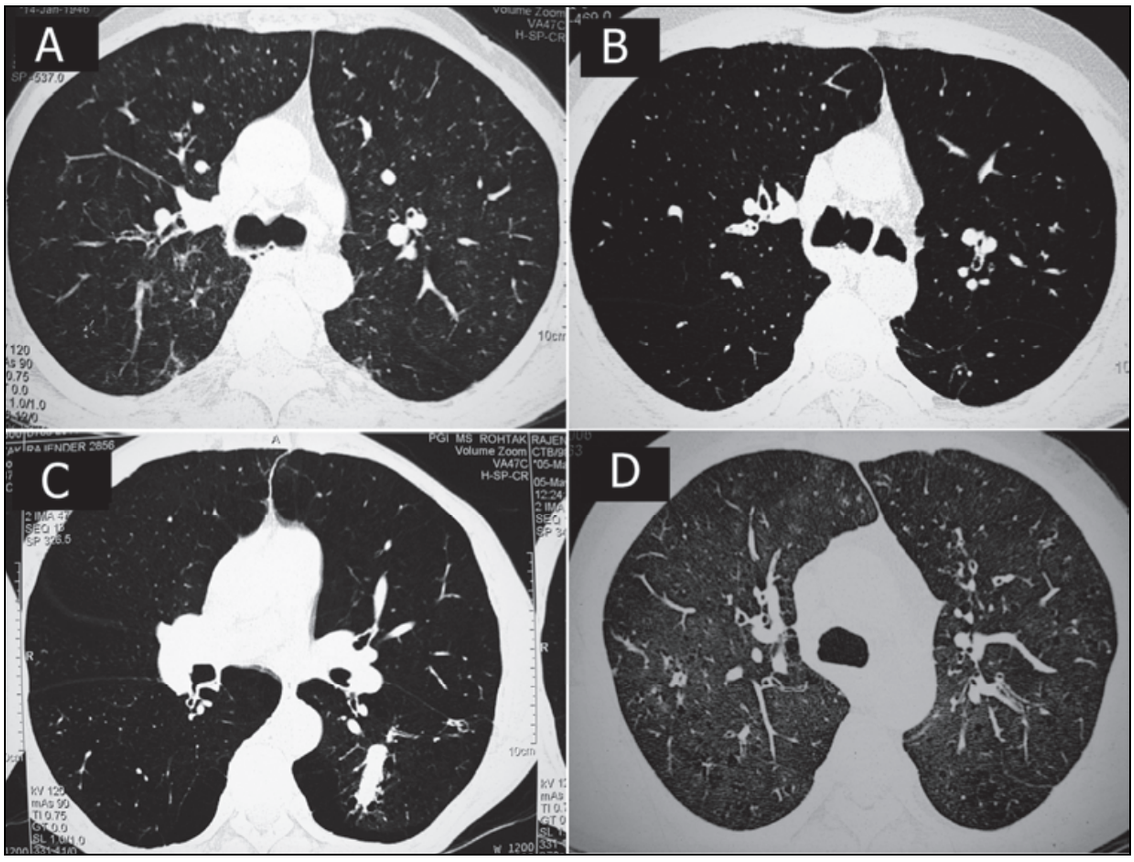


Fig. 9. (A-D): HRCT scans from COPD showing increased sterno-aortic distance and the anterior junctional line.

In a study, AJL and sterno-aortic distance (distance between sternum and ascending aorta) were measured in CT sections at carinal level in 22 patients with emphysema and 22 control subjects (Hagen & Kolebenstvedt 1993). The AJL could be measured in all emphysema patients. In the control group the line was non-existent in 11 of the 22 patients. The AJL was 3 cm or more in 10 of the emphysema patients, but in none of the controls. The sterno-aortic distance was 4 cm or more in 16 of the emphysema patients, but in none among control group. In another study, significant correlation was found between FEV1 / FVC and sterno-aortic distance (measured at tracheal carina on CT) in 74 patients who underwent thoracic surgery for lung cancer (Arakawa et al 1998).

## 12. Thoracic cage ratio and barrel chest

Arakawa et al (1998) measured thoracic cage ratios (anteroposterior/ transverse diameters) at carina and 5 cm below carina on CT in 74 patients. Other measurements of hyperinflation were also calculated and it was found that increased thoracic cage ratio correlated most significantly with a pulmonary functions of chronic airway obstruction.
In another study, normal thoracic cage ratio was 0.70 to 0.75 in adults. The thoracic cage ratio was found high in COPD patients and may reach upto > 0.9 which was called as **barrel chest** (Pierce et al 1958). Figure 10 (A-B) shows HRCT scans with barrel chest feature found in our studies (Gupta et al 2008, 2009).

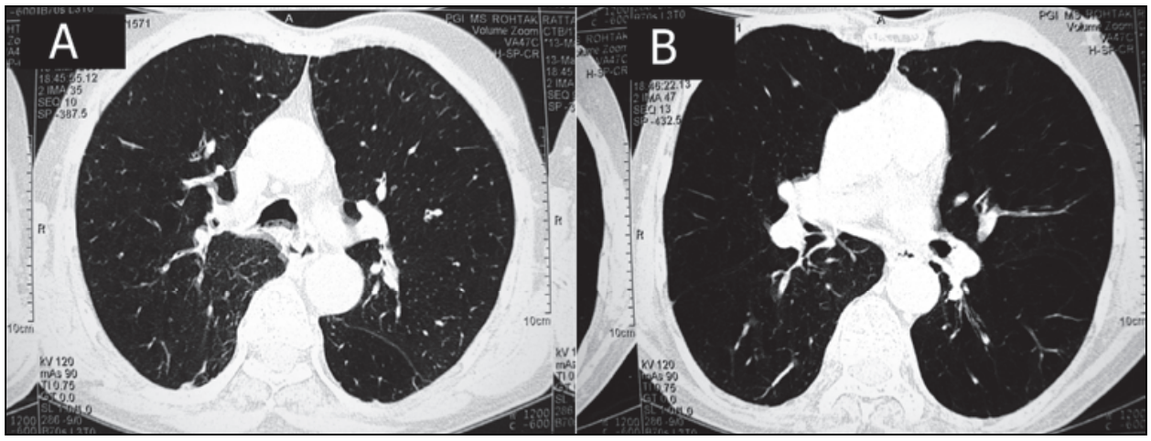


Fig. 10. (A-B): A marked increase in thoracic cage ratio above 0.9 described as barrel chest

## 13. Thoracic cross-sectional area (TCSA) index

The assessment of thoracic cross-sectional area (TCSA) is an important measure of thoracic cage hyperinflation commonly seen in advance COPD with air trapping and increased total lung capacity. TCSA is the area surrounded by the rib cage measured on CT scan made 1 cm below the top of the aortic arch. In a study (Kasai et al 2003) TCSA and pulmonary functions and dyspnea grade were measured in 24 COPD patients. In the group with grade IV dyspnea, the TCSA/ht$^2$ ratios were significantly greater than those in the groups with grade II and III dyspnea, combined. Analysis of data showed a good correlation between TCSA and total lung capacity, as well as functional residual capacity and residual volume.

## 14. HRCT characteristics observed in our studies

Our studies included 40 male patients with COPD. Their mean age was 58.55 years (range: 50-69 years). Total duration of illness due to COPD was in range from 2 to 25 years with a mean of 12.63 years. All subjects were significant smoker with mean smoking history of 33.25 pack years (range 20-74 pack years). They were evaluated for HRCT features including vascular attenuation and distortion, mosaic attenuation pattern, directly visible small airways, low attenuation areas of emphysema and measures of hyperinflation of lungs: tracheal index, sterno-aortic distance, thoracic cage ratio and thoracic cross-sectional area. Individual COPD patients having characteristics HRCT findings were as shown in table-1.

In our studies, tracheal index was observed to have significant inverse correlations with duration of illness, smoking pack years, and dyspnea scale; and had direct correlations with FEV1, PEFR, FEV1/FVC ratio, and FEV1/SVC ratio. Thoracic cage ratio at carina as well as thoracic cage ratio at 5 cm below carina had direct correlations with duration of illness, smoking pack years and dyspnea scale; and had inverse correlations with FEV1, FEV1/FVC ratio and FEV1/SVC ratio. Sterno-aortic distance and thoracic cross sectional area had correlations with duration of illness, smoking pack years and dyspnea scale; and they had inverse correlations with FEV1, FEV1/FVC ratio, and FEV1/SVC ratio.

| HRCT features | Number of patients out of 40 | Percentage of study subjects |
|---|---|---|
| Saber sheath trachea with tracheal index less than 0.67 | 14 | 35 |
| Thoracic cage ratio over 0.75 at the level of carina | 5 | 12.5 |
| Thoracic cage ratio over 0.75 at the level 5 cm below carina | 11 | 27.5 |
| Sterno-aortic distance more than 4 cm | 5 | 12.5 |
| Thoracic cross-sectional area/ht$^2$ more than 80.00 cm$^2$/m$^2$ | 28 | 70 |
| Vascular attenuation | 25 | 62.5 |
| Vascular distortion | 8 | 20 |
| Mosaic attenuation pattern | 16 | 40 |
| Directly visible small airways | 36 | 90 |
| Centriacinar emphysema | 16 | 40 |
| Panacinar emphysema | 11 | 27.5 |
| Paraseptal emphysema | 13 | 32.5 |
| Any type of emphysema | 25 | 62.5 |

Table 1. HRCT features noted in individual COPD patients

Vascular attenuation had significant correlations with duration of illness, dyspnoea scale, smoking pack years, FEV1, FEV1/FVC ratio, and FEV1/SVC ratio. Vascular distortion had no significant correlation with any of the observed parameter. The mosaic attenuation pattern correlated significantly with duration of illness, dyspnea scale, smoking pack years, FEV1, FEV1/FVC ratio, and FEV1/SVC ratio. Correlation of presence of directly visible small airways was significant only with dyspnea scale. Centriacinar emphysema had significant correlations with PEFR, FEV1, FVC, FEV1/FVC ratio and FEV1/SVC ratio. Correlations of presence of any type of emphysema with age, duration, dyspnea scale, pack-years, PEFR, FEV1, FVC, FEV1/FVC ratio and FEV1/SVC ratio were statistically significant.

## 15. Recent advances

COPD is a heterogeneous group of disorders and needs to be evaluated by a combination of morphological and functional assessment. Recently, newer HRCT techniques as well as MRI have provided new insights to characterisation of various pulmonary components of COPD in term of morphology as well as functionality. Three-dimensional HRCT has been described as the technique of choice for morphological imaging. Inspiratory and expiratory 3D-HRCT with volumetric and texture analysis allows for deeper insights to regional hyperinflation and expiratory obstruction. Three-dimensional HRCT has also been described as the "gold standard" for non-invasive quantitative evaluation of airway dimensions. Newer generations of MRI allow for better visual assessment of the lung morphology as well as comprehensive functional imaging. The major advantage of MRI is the assessment of regional lung function including perfusion, respiratory dynamics and ventilation. The comprehensive diagnostic possibilities of CT complemented by MRI will allow for a more sensitive detection, phenotype-driven characterization and dedicated therapy monitoring of COPD.

## 16. Conclusion

While all this description appears voluminous, many things have not been discussed in detail due to want of space. The imaging techniques we are applying in day to day practice at present have opened new avenues for morphological and functional characterisation of various diseases incorporated under the heterogeneous group of COPD and helped in phenotyping as well as assessment of the progression of COPD. And, this is just beginning! In future we are definitely going to get more powerful equipments, supplemented with dedicated and advanced softwares that will provide deeper insight into the various diseases grouped under the umbrella of COPD.

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## 18. References

American Thoracic Society. (1995). Standards for the diagnosis and care of patients with chronic obstructive pulmonary disease. Am J Respir Crit Care Med 152 (5 pt 2): S77-121.

Arakawa H, Webb WR. (1998). Air trapping on expiratory high resolution CT scans in the absence of inspiratory scan abnormalities: correlation with pulmonary function tests and differential diagnosis. Am J Roentgenol 170: 1349-53.

Arakawa H, Kurihara Y, Nakajima Y, Niimi H, Ishikawa T, Tokuda M. (1998). Computed tomography measurements of overinflation in chronic obstructive pulmonary disease: evaluation of various radiographic signs. J Thorac Imaging 13 (3): 188-92.

Aziz ZA, Wells AU, Desai SR, et al. (2005). Functional impairment in emphysema: contribution of airway abnormalities and distribution of parenchymal disease. Am J Roentgenol 185: 1509–15

Bankier AA, De Maertelar V, Keyzer C, et al. (1999). Pulmonary emphysema: subjective visual grading versus objective quantification with macroscopic morphometry and thin-section CT densitometry. Radiology 211: 851–8.

Bergin C, Muller N, Nichols DM. (1986).The diagnosis of emphysema: a computed tomographic pathologic correlation. Am Rev Respir Dis 133: 541-6.

Blechschmidt RA, Werthschutzky R, Lorcher U. (2001). Automated CT image evaluation of the lung: a morphology-based concept. IEEE Trans Med Imaging 20: 434–42.

Boschetto P, Miniati M, Miotto D, et al. (2003). Predominant emphysema phenotype in chronic obstructive pulmonary. Eur Respir J 21: 450–4.

Boschetto P, Quintavalle S, Zeni E, et al. (2006). Association between markers of emphysema and more severe chronic obstructive pulmonary disease. Thorax 61: 1037–42.

Cooper JD, Trulock EP, Triantafillou AN, et al. (1995). Bilateral pneumectomy (volume reduction) for chronic obstructive pulmonary disease. J Thorac Cardiovasc Surg 109: 106–116. (discussion 116–109).

Copley SJ, Wells AU, Muller NL, et al. (2002). Thin-section CT in obstructive pulmonary disease: discriminatory value. Radiology 223: 812–19.

Dawkins PA, Dowson LJ, Guest PJ, et al. (2003). Predictors of mortality in alpha-1-antitrypsin deficiency. Thorax 58: 1020–6.

de Jong PA, Muller NL, et al. (2005). Computed tomographic imaging of the airways: relationship to structure and function. Eur Respir J 26: 140–52.

Desai SR, Hansell DM, Walker A, MacDonald SL, Chabat F, Wells AU. (2007). Quantification of emphysema: A composite physiologic index derived from CT estimation of disease extent. Eur Radiol 17: 911–8.

Deveci F, Murat A, Turgut T, Altuntas E, Muz MH. (2004). Airway wall thickness in patients with COPD and healthy current smokers and healthy non-smokers: assessment with high resolution computed tomographic scanning. Respiration 71: 602-10.

Fishman A, Martinez F, Naunheim K, et al. (2003). A randomized trial comparing lung-volume reduction surgery with medical therapy for severe emphysema. N Engl J Med 348: 2059–73.

Gevenois PA, De Vuyst P, de Maertelaer V, et al. (1996). Comparison of computed density and microscopic morphometry in pulmonary emphysema. Am J Respir Crit Care Med 154: 187–92.

Gevenois PA, Scillia P, De Maertelaer V, et al. (1996). The effects of age, sex, lung size, and hyperinflation on CT lung densitometry. Am J Roentgenol 167: 1169–73.

Gould GA, MacNee W, Mclean A. (1988). CT measurements of lung density in life can quantitate distal airspace enlargement: an essential defining feature of human emphysema. Am Rev Resp Dis 133: 380-92.

Grenier PA. (2005). Detection of altered lung physiology. Eur Radiol 15: 42–7.

Grenier PA, Beigelman-Aubry C, Fetita C, et al. (2004). Large airways at CT: Bronchiectasis, Asthma and COPD. In: Kauczor HU, editor. Functional imaging of the chest. Heidelberg: Springer; pp. 39–55.

Griffen CB, Primack SL. (2001). High resolution CT: Normal anatomy, techniques and pitfalls. Radiologic Clinic of North America 39 (6): 1073-90.

Group NETTR. (2001). Patients at high risk of death after lung-volume reduction surgery. N Engl J Med 345: 1075–83.

Gupta PP, Yadav R, Verma M, Gupta KB, Agarwal D. (2009). High resolution computed tomography features in patients with chronic obstructive pulmonary disease. Singapore Med J 50: 193-200.

Gupta PP, Yadav R, Verma M, Agarwal D, Kumar M. (2008). Correlation between high resolution computed tomography features and patients` characteristics in chronic obstructive pulmonary disease. Annals Thorac Med 3: 87-93.

Hagen G, Kolebenstvedt A. (1993). CT measurement of mediastinal anterior junction line in emphysema patients. Acta Radiologica 34: 194-5.

Hansell DM. (2001). Small airways diseases: detection and insights with computed tomography. Eur Respir J 17: 1294–1313.

Hoffman EA, Simon BA, McLennan G. (2006). State of the art. A structural and functional assessment of the lung via multidetector-row computed tomography: phenotyping chronic obstructive pulmonary disease. Proc Am Thorac Soc 3: 519–32.

Kasai T, Yamada M, Narushima M, Suzuki H. Relationship between thoracic cross-sectional area measured on CT and pulmonary function or dyspnea in patients with COPD. Nihon Kokyuki Gakkai Zasshi 2003; 41:526-30.

Klein JS, Gamsu G, Webb WR, Golden JA, Muller NL. (1992). High resolution CT diagnosis of emphysema in symptomatic patients with normal chest radiographs and isolated low diffusing capacity. Radiology 182: 817-21.

Kuhnigk JM, Dicken V, Zidowitz S, et al. (2005). Informatics in radiology (infoRAD): new tools for computer assistance in thoracic CT. Part 1. Functional analysis of lungs, lung lobes, and bronchopulmonary segments. Radiographics 25: 525–36.

Kurashima K, Takayanagi N, Sato N, et al. (2005). High resolution CT and bronchial reversibility test for diagnosing COPD. Respirology 2005; 10: 316–22.

Kuwano K, Matsuba K, Ikeda T, et al. (1990). The diagnosis of mild emphysema: correlation of computed tomography and pathology scores. Am Rev Respir Dis 141: 169-78.

Lamers RJ, Thelissen GR, Kessels AG, Wouters EF, van Engelshoven JM. (1994). Chronic obstructive pulmonary disease: evaluation with spirometrically controlled CT lung densitiometry. Radiology 193: 109-13.

MacNee W, Gould G, Lamb D. (1991). Quantifying emphysema by CT scanning: clinical-pathological correlates. Ann N Y Acad Sci 624: 179-194.

Martinez FJ, Foster G, Curtis JL, et al. (2006). Predictors of mortality in patients with emphysema and severe airflow obstruction. Am J Respir Crit Care Med 173: 1326–34.

Martinez FJ, Chang A. (2005). Surgical therapy for chronic obstructive pulmonary disease. Semin Respir Crit Care Med 26: 167–191.

Morgan MDL. (1992). Detection and quantification of pulmonary emphysema by computed tomography: a window of opportunity. Thorax 47: 1001-4.

Muller NL, Staples CA, Miller RR. (1998). "Density mask". An objective method to quantitate emphysema using computed tomography. Chest 94: 782-7.

Muller NL, Coxson H. (2002). Chronic obstructive pulmonary disease. 4: imaging the lungs in patients with chronic obstructive pulmonary disease. Thorax 57: 982–5.

Nakano Y, Sakai H, Muro S, et al. (1999). Comparison of low attenuation areas on computed tomographic scans between inner and outer segments of the lung in patients with chronic obstructive pulmonary disease: incidence and contribution to lung function. Thorax 54: 384–9.

Nakano Y, Muro S, Sakai H, et al. (2000). Computed tomographic measurements of airway dimensions and emphysema in smokers. Correlation with lung function. Am J Respir Crit Care Med 162: 1102–8.

Nakano Y, Wong JC, de Jong PA, et al. (2005). The prediction of small airway dimensions using computed tomography. Am J Respir Crit Care Med 171: 142–6.

Nowell Jr JD. CT of emphysema. (2002). Radiologic Clinics of North America 40 (1): 31-42.

O'Brien C, Guest PJ, Hill SL, et al. (2000). Physiological and radiological characterisation of patients diagnosed with chronic obstructive pulmonary disease in primary care. Thorax. 55: 635–42.

Orlandi I, Moroni C, Camiciottoli G, et al. (2005). Chronic obstructive pulmonary disease: thin section CT measurement of airway wall thickness and lung attenuation. Radiology 234: 604-10.

Patel IS, Vlahos I, Wilkinson TM, et al. (2004). Bronchiectasis, exacerbation indices, and inflammation in chronic obstructive pulmonary disease. Am J Respir Crit Care Med 170: 400–7.

Patel B, Make B, Coxson HO, et al. (2006). Airway and parenchymal disease in chronic obstructive pulmonary disease are distinct phenotypes. Proc Am Thorac Soc 3: 533.

Pauwels RA, Buist AS. (2001). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease. NHLBI/WHO Global Initiative for Chronic Obstructive Lung Disease (GOLD) Workshop summary. Am J Respir Crit Care Med 163: 1256–76.

Pierce JA, Ebert RV. (1958). The barrel deformity of the chest, the senile lung and obstructive pulmonary emphysema. Am J Med 25: 13-22.

Sanders C, Nath PH, Bailey WC. (1988). Detection of emphysema with computed tomography: correlation with pulmonary function tests and chest radiography. Invest Radio 23: 262-6.

Stern EJ, Frank MS. (1994). Small airway diseases of the lungs: Findings at expiratory CT. Am J Roentgenol 163: 37-41.

Sverzellati N, Molinari F, Pirronti T, Bonomo L, Spagnolo P, Zompatori M. (2007). New insights on COPD imaging via CT and MRI. Intern J COPD 2 (3): 301–12.

Teel GS, Engeler CE, Tashijian JH. (1996). Imaging of small airways disease. Radiographics 16: 27-41.

Thurlbeck WM. (1994). Emphysema then and now. Can Respir J 1: 21–39.

Trigaux JP, Hermes G, Dubois P, et al. (1994). CT of saber-sheath trachea. Correlation with clinical, chest radiographic and functional findings. Acta Radiol 35 (3): 247-50.

Tsao TC, Shieh WB. (1994). Intrathoracic tracheal dimensions and shape changes in chronic obstructive pulmonary disease. J Formos Med Assoc 93 (1): 30-4.

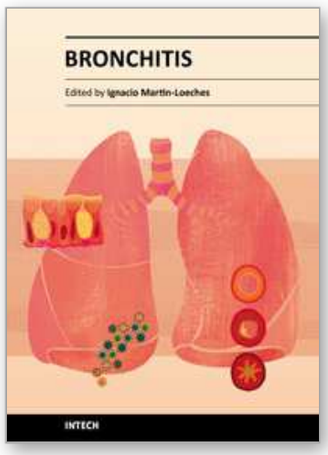
Uppaluri R, Mitsa T, Sonka M, et al. (1997). Quantification of pulmonary emphysema from lung computed tomography images. Am J Respir Crit Care Med 156: 248–54.

Uppaluri R, Hoffman EA, Sonka M, et al. (1999). Computer recognition of regional lung disease patterns. Am J Respir Crit Care Med 160: 648–54.

Zagiers H, Vrooman HA, Aarts NJM, et al. (1996). Assessment of the progression of emphysema by quantitative analysis of spirometrically gated computed tomography images. Invest Radiol 31: 761-7.

Zaporozhan J, Ley S, Eberhardt R, et al. (2005). Paired inspiratory/expiratory volumetric thin-slice CT scan for emphysema analysis: comparison of different quantitative evaluations and pulmonary function test. Chest 128: 3212–20.

Zompatori M, Sverzellati N, Gentile T, et al. (2006). Imaging of the patient with chronic bronchitis: an overview of old and new signs. Radiol Med 111: 634–9.




**Bronchitis**

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Lung parenchyma has been extensively investigated. Nevertheless, the study of bronchial small airways is much less common. In addition, bronchitis represents, in some occasions, an intermediate process that easily explains the damage in the lung parenchyma. The main target of this book is to provide a bronchial small airways original research from different experts in the field.



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