Original Article

Correlation of Physiological and Radiological Characteristics in Chronic Obstructive Pulmonary Disease

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ABSTRACT

Background. Diagnosis of chronic obstructive pulmonary disease (COPD) is confirmed on spirometry but the diagnosis of emphysema remains problematic. The objective of this study was to evaluate the utility of chest radiograph (CXR) and computed tomography (CT) for the diagnosis of emphysema and to correlate these findings with pulmonary function tests (PFTs).

Methods. Thirty-five patients with COPD were studied. In all of them, CXR, CT and PFTs were done; three patients had bronchiectasis on CT and were excluded from the study. Chest radiographs (CXRs) were scored for signs of hyperinflation. Lung densities were measured on CT.

Results. Functional indices of hyperinflation, i.e. functional residual capacity (FRC), residual volume (RV) and RV/total lung capacity (TLC) had significant correlation with CXR scores. The mean retrosternal space (RSP) measurement was 2.63±0.6 cm (range 1.2 to 3.6cm). Mean lung density (MLD) was -867.91 Hounsfield units (HU) which significantly correlated with functional indices of hyperinflation (FRC, RV, TLC, RV/TLC).

Conclusions. In Indian population hyperinflation was found to occur even with lesser values of RSP than the western criteria. CT lung density gives good radiological evidence of emphysema and correlates with lung function abnormalities.
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Key words: Chest radiograph, Computed tomography, CT lung density, Emphysema, PFTs.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is defined[1] as a "disease state characterised by airflow limitation that is not fully reversible. The airflow limitation is usually both progressive and associated with an abnormal inflammatory response of the lungs to noxious particles or gases." COPD is an important cause of morbidity and mortality worldwide.[1] Recent studies have suggested that mortality from COPD may still be increasing, especially in the older age group.[2]

Diagnosis of COPD is confirmed on spirometry but diagnosis of emphysema remains problematic. Different modalities have been used in various ways to accurately assess the extent and severity of emphysema. Chest radiograph (CXR) showing signs of hyperinflation, such as increased lung volumes, low flat diaphgram, increased retrosternal space or signs of destruction such as decreased vascular markings, bullae etc., may be helpful in detecting emphysema but the usefulness is limited.[3,4] Spirometry, along with measurements of static lung volumes and diffusion has been found to be a very sensitive indicator of emphysema. Severe emphysema typically causes airflow limitation, air trapping, and diminished diffusion capacity.[5,6] However, patients with severe emphysema may remain asymptomatic with minimal or no functional abnormalities.[7,8] Most series show a progressive decrease in forced expiratory volume in the first second (FEV_1)/forced vital capacity (FVC) ratio and diffusion capacity with worsening degrees of emphysema at autopsy.[9] Diffusion capacity appears to be related best to the severity of emphysema.[8,10,11] In recent years, computed tomography (CT) has been considered as the most sensitive method for detecting emphysema in life. It helps in assessment of subtypes and extent of emphysema. Extent of emphysema can be found either by visual scoring or by measuring lung density.[12-16]

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The attenuation value [expressed in Hounsfield (HU) units] of a pixel has a linear relationship with the physical density of the tissue, comprised in the voxel.[17] The air-tissue ratio in emphysematous lung increases, and therefore, its physical density decreases. Consequently, CT density of the lung can be expected to decrease in proportion to the amount of emphysema present. However, assessment of the pathological sections for emphysema remains the *Gold Standard*.

MATERIAL AND METHODS

Study Subjects

We recruited 43 male patients with COPD during 2003 to 2004 from the out-patient department of our Institute who were relatively stable, ambulatory and co-operative and had fixed airflow limitation. Of these, 35 gave consent for undergoing all the investigations and were included for the study. Patients were included in the study after they fulfilled the following criteria: cough with expectoration for most of the days for at least three months of the year for at least two successive years; history of smoking (≥10 pack years), past or present; history of exertional dyspnoea; FEV_1 less than 80% of predicted, with a FEV_1/FVC ratio less than 70%; and a difference between pre-bronchodilator and post-bronchodilator values of FEV_1 not exceeding 15%; CXR (postero-anterior [PA)]) and left-lateral views showing no evidence of an acute infection or any other pulmonary diseases. Brinkman index (BI)[18] obtained by multiplying the number of cigarette per day by the duration of the smoking in years was also calculated for all the patients.

They were excluded if the following were present: past or present pulmonary tuberculosis; history suggestive of asthma; presence of ischaemic heart disease or overt left ventricular failure; recent (within 4 weeks) hospitalisation for COPD exacerbation. Informed consent was obtained from all the patients. The Ethics Committee of our institution approved the study protocol.

Study Design

All 35 patients underwent complete pulmonary function testing, Chest radiograph (postero-anterior and left-lateral views) and CT (thorax) within a span of three to four days. Three patients in whom CT showed evidence of bronchiectasis were excluded from the final analysis.

Pulmonary Function Tests

Pulmonary function testing was performed on a computerised Transfer test model "C" (P.K. Morgan and Co. Ltd, Chatham, Kent England). Maximal expiratory flow volume loops were obtained on the dry rolling seal spirometer. FVC, FEV_1, maximal expiration flow rate (FEF_{max}) and forced expiratory flow after 25% of the FVC has been exhaled ($FEF_{25\%}$), forced expiratory flow after 50% of the FVC has been exhaled ($FEF_{50\%}$), average forced expiratory flow rate over the middle 50% of the FVC ($FEF_{25-75\%}$), forced expiratory time (FET), were measured using the selection criteria of the American Thoracic Society (ATS).[19] The reference equations given by Knudson *et al*[20] were used for calculating percent predicted values of the spirometry parameters.

Functional residual volume (FRC) was measured using the close circuit helium (He) dilution technique (helium with known concentration of 12%-14%). The initial volume of gas to which helium was added, was measured and recorded beforehand. The subject was connected to the circuit at the end expiratory position during tidal breathing and re-breathed the gas mixture until the concentration of He decreased to a stable level (usually in 5-7 minutes). The final concentration of He recorded and FRC was computed as:

$$FRC = \frac{\%\ He\ Initial - \%\ He\ Final}{\%\ He\ Final} X\ Initial\ Volume$$

Residual volume (RV) was obtained by subtracting expiratory reserve volume from FRC and total lung capacity (TLC) was calculated by adding vital capacity to RV. Single breath modified Krogh technique[21] was used to determine lung diffusion for carbon monoxide (DLco). Starting from the position of residual volume, the subjects inspired a vital capacity breath from a bag containing a gaseous mixture of carbon monoxide (CO) (0.28%), He (14%), oxygen (80%) and the rest being constituted by nitrogen, and then, held their breath for 10 seconds. Then, after an initial washout of dead space gas, a sample of alveolar gas was taken with an end tidal sample from the expired air and analysed to obtain the final fraction of CO and He concentration. Alveolar volume (VA) was calculated from the inspired volume and the initial and final He concentrations by a method similar to the closed determination of FRC. Diffusion per unit volume (KCO) was calculated as DLco/VA. PFT was carried out in the morning and the patient was not to take any bronchodilator on the day before the test. European Community for Steel and Coal (ECCS) reference equations were used for calculating percent predicted values of both lung volumes[22] and diffusing capacity.[23] We used functional definition of emphysema as suggested by the ATS[5]: evidence of obstructive lung disease (FEV_1 <80% and/or RV >120% of predicted values) plus decreased corrected DLco (<80% of predicted), to define emphysema on PFT.

Patients were divided into different groups on the basis of PFT results. All the patients studied had fixed airflow obstruction FEV_1/FVC less than 70%. Group A (n=12) had moderate obstruction (50%≤FEV_1<80% predicted), Group B (n=16) had severe obstruction (30%≤FEV_1<50% predicted) and Group C (n=4) had very severe obstruction (FEV_1<30% predicted) as per Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria.[1] Since group C consisted of only four patients, groups B and C were merged to form group D (n=20) for the purpose of analysis.

Patients were further divided into two groups, as per ATS criteria.[5] Group X (n=26) consisted of patients with FEV_1/FVC<70%, together with DLco<80% and/or RV>120%, i.e. patients with functional characteristics of emphysema. Group Y (n=6) had FEV_1/FVC<70% and/or RV>120% but normal DLco (DLco≥80%), thus, being considered to have COPD without functional emphysema.

Chest Radiography

The CXRs were obtained with the patient's upright, holding their breath at full inspiration. A standardised 2-meter focus to film distance was used. Exposure time was kept as short as possible to reduce motion un-sharpness. Kilovoltage was adjusted to each patient's body build. The CXRs were taken within 48 hours of performing the PFT. The CXRs were independently read by two observers (one chest physician and one radiologist) without the knowledge of functional studies or CT findings. Measurements were carried out as shown in the figure. For the analysis; a reading table was used (Table 1) that included the evaluation of CXR for signs of hyperinflation and of pulmonary vascular abnormalities known to be associated with emphysema. Signs of hyperinflation, i.e. right diaphragm height (DMHT) (indicative of flattening of the dome of diaphragm), right lung length (LL), level of right dome of diaphragm (DML), retrosternal space (RSP) were measured and scored. These parameters were defined as follows:

The DMHT was calculated from measurements of a line perpendicular from the top of dome of the right diaphragm to a line joining the costophrenic and cardiophrenic angles.

The LL was calculated as the distance from tubercle of first rib to the top of the dome of right diaphragm.

The DML was calculated as the level of the apex of the right diaphragm in relation to anterior rib.

RSP was measured as the horizontal distance from the posterior aspect of the sternum 3cm below the sternoclavicular junction to the anterior margin of the aorta.

For the evaluation of pulmonary vascular abnormalities, the PA film was divided in four quadrants at the level of carina.[24] Each quadrant was analysed for the presence of any vascular abnormalities and was scored as 0 or 0.5. The partial scores from four quadrants were summed and cumulative emphysema score ranged from 0 to 12. Any difference in scores was averaged and if difference was greater than 2, CXR was again read and consensus score obtained.

Table 1. Criteria to evaluate emphysema on the chest radiograph

Chest Radiographic Findings		Score
Level of right dome of diaphragm (DML)	**Score**	
≤6th rib	0	0 – 3
>6th rib - ≤7th rib	1	
>7th rib - ≤8th rib	2	
>8th rib	3	
Height of right dome of diaphragm (DMHT)		
>1.5cm	0	0 – 2
≤1.5cm - >1cm	1	
≤1cm	2	
Retrosternal space (RSP)		
<2.5cm	0	0 – 3
≥2.5cm - <3.0cm	1	
≥3.0cm - <3.5cm	2	
≥3.5cm	3	
Signs of vascular deficiency (DTRN-S)		
Widening of normal peripheral clear zone of lung		0 or 0.5
Loss of normal background pattern and increased lucency of the lung		0 or 0.5

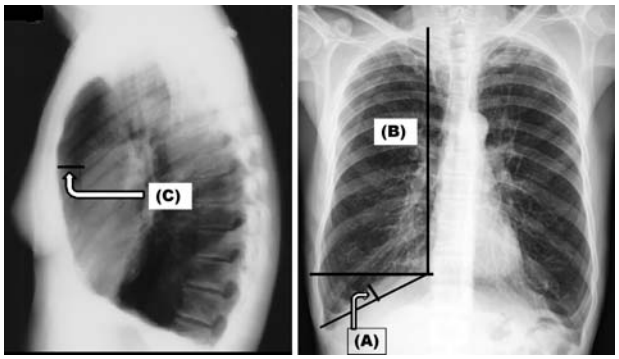

Figure. The measurements were made with an ordinary transparent ruler having 1mm increments. Different radiographic measurements were obtained as: (A) *Right diaphragmatic height (DMHT)* — measurements of a line perpendicular, from the top of dome of the right diaphragm, to a line joining the costophrenic and cardiophrenic angles; (B) *Right lung length (LL)* — distance from tubercle of 1st rib to the top of the dome of right diaphragm; (C) *Retrosternal space (RSP)* — horizontal distance from the posterior aspect of the sternum 3cm below the manubriosternal junction to the anterior margin of the aorta.

Computed Tomography

Patients were scanned using a Siemens Somatom Plus 4, CT scanner (thickness 10mm, 125kv, 280mAs). Scanning was done during breath holding after full inspiration. Hard copy images were photographed using settings appropriate for the lung (level –600HU, width 1200HU). To measure lung density, method described by Heremans *et al*[25] was used. The mean lung densities (MLDs) were determined by the sector method, and by the whole lung field method (MLDw). Scans were studied at three levels: at the level of sternoclavicular joint; at the level of carina; and through the lung bases at about 2cm above the upper part of diaphragm. For MLDs, ovoid cursor of 300 pixels was placed on each scan level in the periphery of two lung fields, both anteriorly and posteriorly. Care was taken to avoid vessels, any lesions or blebs. The mean attenuation within each cursor was obtained and the values from the 12 peripheral lung regions sampled in each patient were averaged to obtain MLDs. For MLDw, both lung fields on the same scan were outlined manually, avoiding the dense central hilar region and the mean attenuation within the each lung field was measured. Again the values were averaged to obtain the mean MLDw. Mean MLDs and MLDw were averaged to obtain mean lung density (MLD) value. Attenuation values were expressed in HU where 0HU represents the density of water and –1000HU the density of air. CT was also looked for emphysema visually and other associated findings, such as bronchiectasis, bullae, fibrosis etc. Two observers also read CT independently and blindly.

Statistical Analysis

Correlations were computed using Pearson's coefficient. Different parameters of CXR, PFT and CT lung density measurements were compared among groups (A and D), using 'unpaired' t-test. Significance in various CXR, PFT and CT lung density parameters were compared among groups (X and Y) using 'unpaired' t-test. A 'p' value less than 0.05 was considered significant. Statistical analysis was carried out with the help of Statistical Package for the Social Sciences (SPSS) (version 14.0) for Windows.

RESULTS

Baseline and functional characteristics of 32 male patients with COPD are shown in table 2. By selection criteria, all the patients had fixed airflow obstruction. The degree of airflow obstruction ranged from moderate to very severe but DLco and KCO ranged

Table 2. Baseline characteristics and pulmonary function testing parameters of the patient population (n=32)

Variable	Mean±SD	Minimum	Maximum	Range
Age (years)	61.50±9.788	41.00	78.00	37.00
Height (cm)	1.65±0.059	1.54	1.79	0.25
Weight (Kg)	54.46±9.58	39.00	73.00	34.00
BMI (Kg/m^2)	19.84±3.28	14.32	26.81	12.49
Smoking (pack years)	42.49±23.08	14.00	125.00	111.00
Brinkman index (18)	850.50±462.46	280.00	2,500.00	2,200.00
FVC*	77.68±14.55	56.00	116.00	60.00
FEV_1*	46.28±14.36	19.00	72.00	53.00
FEV_1/FVC (%)	59.03±12.02	29.00	81.00	52.00
FEF_{max}*	40.87±13.38	23.00	72.00	49.00
FEF_{25-75}*	17.12±9.35	6.00	43.00	37.00
FRC*	107.34±22.98	69.00	157.00	88.00
TLC* %	95.09±15.77	68.00	130.00	62.00
RV*	119.87±37.95	68.00	214.00	146.00
RV/ TLC (%)	136.21±29.52	85.00	207.00	122.00
DL_{CO}*	64.37±22.99	19.00	112.00	93.00
KCO*	91.62±32.66	27.00	177.00	150.00

*=expressed as % predicted

SD=Standard deviation; BMI=Body mass index; FVC=Forced vital capacity; FEV_1=Forced expiratory volume in the first second; FEF_{max}=Maximal expiration flow rate; FEF_{25-75}=Average forced expiratory flow rate over the middle 50% of the FVC; FRC=Forced residual capacity; TLC=Total lung capacity; RV=Residual volume; RV/TLC%=Residual volume/ Total lung capacity ratio; DL_{CO}=Diffusion capacity of carbon monooxide; KCO=Diffusion per unit volume

from normal to markedly reduced. The CXR and CT lung density measurements are shown in table 3. Mean CXR score was 4.00±1.75. Maximal RSP measured was 3.60cm (mean 2.63±0.60cm). On studying lung densities, mean MLDs was -868.96±27.65HU and MLDw was -868.99±27.57HU and no significant correlation was found with age. Good correlation was found between two methods (MLDs and MLDw) used for density measurement (r=0.990; p<0.01).

CXR score and functional parameters that express hyperinflation (FRC, RV, RV/TLC). However, the score did not correlate with DLco or KCO. Significant correlation was found between CT lung density and functional parameters expressing obstruction (FEV_1, FEF_{max}, $FEF_{25-75\%}$); hyperinflation (FRC, RV, RV/TLC) but the correlation was not observed with diffusion parameters (DLco and KCO).

Table 5 shows characteristics like age, body mass index (BMI), pack years, CXR score, CT lung density measurements and their statistical significance among group A and D. The groups were matched for age, sex, BMI and number of pack years. There was no statistically significant difference of CXR score among group A and D. However, there was statistically significant difference of MLD among group A and D. When the patients were divided into groups X and Y (on the basis of impaired diffusion),

Table 3. Chest radiograph and computed tomographic density characteristics of the patient population (n=32)

Variable	Mean±SD	Minimum	Maximum	Range
DMHT (cm)	1.58±0.31	0.90	2.20	1.30
LL (cm)	24.78±1.94	19.70	27.80	8.10
DML	6.62±0.56	5.00	7.50	2.50
RSP (cm)	2.63±0.60	1.20	3.60	2.40
DTRN-S	1.65±1.011	0.00	4.00	4.00
CXR score	4.00±1.75	1.00	8.00	7.00
MLDs (HU)	-868.96±27.65	-945.58	-832.25	113.32
MLDw (HU)	-868.99±27.57	-946.56	-829.43	117.13
MLD (HU)	-867.91±31.00	-943.61	-820.88	122.73

SD=Standard deviation; DMHT=Height of right dome of diaphragm; LL=Right lung length; DML=Level of right dome of diaphragm; RSP=Retrosternal space; DTRN-S=Signs of vascular deficiency; CXR=Chest radiograph; MLDs=Mean lung density by the sector method; MLDw=Mean lung density by the whole lung method; MLD=Mean value of MLDs and MLDw; HU=Hounsfield units

Correlation between CXR score, CT lung densities and functional parameters is shown in table 4. Significant positive correlation was found between

Table 4. Correlation of CXR score and CT lung density with PFT parameters

Variable	CXR Score	MLDs	MLDw	MLD
FVC*	-0.211	0.351†	0.348	0.357†
FEV_1*	-0.154	0.380†	0.411†	0.341
FEV_1/FVC (%)	-0.050	0.29†	0.351†	0.219
FEF_{max}*	-0.211	0.436†	0.420†	0.384†
FEF_{25-75}*	-0.238	0.363†	0.394†	0.331
FRC*	0.457‡	-0.608‡	-0.599‡	-0.674‡
TLC*	0.224	-0.308	-0.332	-0.368†
RV*	0.489‡	-0.678‡	-0.697‡	-0.759‡
RV/TLC (%)*	0.411†	-0.732‡	-0.755‡	-0.767‡
DL_{CO}*	-0.121	0.274	0.227	0.268
KCO*	-0.098	0.255	0.181	0.280

*=expressed as % predicted; †p < 0.05; ‡p < 0.01

CXR=Chest radiograph; CT=Computed tomography; PFT=Pulmonary function test; MLDs=Mean lung density by the sector method; MLDw=Mean lung density by the whole lung method; MLD=Mean value of MLDs and MLDw; FVC=Forced vital capacity; FEV_1=Forced expiratory volume in the first second; FEF_{max}=Maximal expiration flow rate; FEF_{25-75}=Average forced expiratory flow rate over the middle 50% of the FVC; FRC=Functional residual capacity; TLC=Total lung capacity; RV=Residual volume; RV/TLC(%)=Percent predicted of residual volume/Total lung capacity; DL_{CO}=Diffusion capacity of carbon mono-oxide; KCO= Diffusion per unit volume

Table 5. Comparison of different parameters with increasing severity of FEV_1

Variable	Group A (n=12)	Group D (n=20)	p-value
Age (years)*	64.91±8.93	59.45±9.91	NS
Pack years*	45.6±28.82	40.63±19.47	NS
BMI (Kg/m^2)*	21.40±3.31	18.90±2.95	NS
CXR score*	3.20±1.37	4.47±1.81	NS
MLDs (HU)*	-855.64±17.87	-876.95±29.72	NS
MLDw (HU)*	-854.92±19.50	-877.43±28.63	NS
MLD (HU)*	-853.13±20.34	-876.77±33.29	p<0.05

*=expressed as mean±SD

Group A=50% ≤ FEV_1 < 80% predicted; Group D includes groups B (30% ≤ FEV_1 < 50% predicted) and group C (FEV_1 < 30% predicted)

FEV_1=Forced expiratory volume in the first second; BMI=Body mass index; CXR=Chest radiograph; MLDs=Mean lung density by the sector method; MLDw=Mean lung density by the whole lung method; MLD=Mean value of MLDs and MLDw; NS=Not significant

there was statistically significant difference in MLD in the two groups with MLD in group X being -872.74±30.27 and in group Y being -846.98±27.04 ($p<0.05$) (Table 6). RV/ TLC (% predicted) was higher in group X (140.34±27.09) compared to the group Y (118.33±35.53) but the difference was not statistically significant. No difference in CXR score was obtained between the two groups. Suspected malignancy was not found on CT in any of the 32 patients.

Table 6. Comparison of different parameters between groups X and Y

Variable	Group X (n = 26) †	Group Y (n = 6) †	p-value
FEV_1*	45.42±13.02	50.00±20.42	NS
FVC*	76.11±13.97	84.50±16.37	NS
FEV_1/FVC (%)	59.26±11.05	58.00±16.85	NS
TLC*	94.92±15.65	95.83±17.80	NS
RV*	121.88±34.77	111.16±52.68	NS
RV/TLC (%)	140.34±27.09	118.33±35.53	NS
CXR Score	4.00±1.84	4.00±1.41	NS
MLDs (HU)	-872.88±28.33	-851.97±17.34	NS
MLDw (HU)	-872.20±28.18	-855.07±21.35	NS
MLD (HU)	-872.74±30.27	-846.98±27.04	p<0.05

*=expressed as % predicted; †=expressed as mean±SD

Group X=FEV_1/FVC < 70% and DL_{CO} < 80% and/or RV > 120%; Group Y=FEV_1/FVC < 70% and DL_{CO} ≥ 80% and/or RV > 120%

FVC=Forced vital capacity; FEV_1=Forced expiratory volume in the first second; FEF_{max}=Maximal expiration flow rate; FEF_{25-75}=Average forced expiratory flow rate over the middle 50% of the FVC; FRC=Functional residual capacity; TLC=Total lung capacity; RV=Residual volume; RV/TLC(%)=Percent predicted of residual volume/Total lung capacity; DL_{CO}=Diffusion capacity of carbon mono-oxide; KCO=Diffusion per unit volume; CXR=Chest radiograph; MLDs=Mean lung density by the sector method; MLDw=Mean lung density by the whole lung method; MLD=Mean value of MLDs and MLDw

DISCUSSION

Emphysema is defined pathologically, as permanent abnormal enlargement of airspaces distal to the terminal bronchiole accompanied by destruction of alveolar walls and without obvious fibrosis.[26] Conventional chest radiography is reportedly considered to be of little diagnostic value. PFT is considered to be a useful investigation for detecting emphysema. CT scanning is a sensitive technique capable of detecting emphysematous lesions as small as 0.5cm in diameter.[27] The CXR score of emphysema, used in the present study, based on the combined evaluation of hyperinflation and vascular deficiency, showed significant correlation with the functional indices of hyperinflation (RV and RV/TLC [% predicted]) but not with impaired diffusion (DLco or KCO [% predicted]). These findings were similar to the observations reported by Thurlbeck and Simon[28] who observed that using vascular deficiency as the primary radiographic finding for emphysema, correct diagnosis of emphysema was obtained in only 41% of patients with moderately severe or very severe emphysema. In our study, maximum LL attained was 27.8cm, as against other studies[29,30] that mentioned LL of more than 29.9cm to be an indicator of hyperinflation and obstruction. Mean of LL, in our study attained was 24.78±1.94 cm. Mean RS noted in our patients with COPD was 2.63±0.60 cm as against a RS depth of more than 4.4cm that would predict obstruction and hyperinflation in other studies.[29,31] The objective radiological markers of hyperinflation in Indian patients having COPD, thus, differ from that of western criteria. Larger studies are needed to define new criteria for defining hyperinflation on CXR in Indian patients.

The CT can be used to study pulmonary emphysema by visual analysis of lung images at the appropriate windows, or by the CT density measurements of lung parenchyma. However, a number of factors can influence the absolute CT density number, such as type of CT scanner, kilovoltage, and reconstruction algorithm.[7,26] Further, to grade emphysema on CT requires a specialist chest radiologist. Subjective grading of emphysema has been found to be significantly less accurate than objective CT densitometry results.[32] To avoid inter-observer and intra-observer variability we used objective method of measuring emphysema and all the CT recordings were done on the same scanner under similar conditions. We observed a perfect linear correlation between MLDs and MLDw and this observation was consistent with the results of Hermans *et al*.[25] So, the chance of occurrence of a sampling error was minimised. The mean MLDs, MLDw and MLD values in our patients having COPD were much less than the lung density in normal persons (–746±44HU for men).[33]

Gould *et al*[34] were the first to publish significant correlation between CT densitometry and pathologic examination of the resected lung specimens for emphysema in a large group of patients. They later also showed a significant correlation between density index and KCO in 97 patients.[35] It has also been found in various studies[32,36,37] that CT density decreases with increasing severity of emphysema. In our study, significant correlations were found between six PFT parameters (FVC, FEF_{max}, FRC, TLC, RV, RV/ TLC) and MLD. These results are similar to the other studies.[25,38-40]

No correlation was found between lung density and age in our study. This is consistent with the results of Rosenblum *et al*[17] who also did not find any correlation between mean lung density and age in 19 subjects more than 10 years old. We were able to demonstrate that as the severity of fall in FEV_1 (%

predicted) increases, the lung density decreases. There was difference among patients with moderate *versus* severe and very severe obstruction in terms of MLDs, MLDw and MLD (group A and D) with decrease in density measurements with increased severity of obstruction. Although the difference was statistically significant only in case of MLD. On classifying patients into two groups based on ATS criteria (group X and Y), difference in RV/TLC (% predicted), MLDs, MLDw and MLD was also found (Table 6). Again the statistically significant difference was observed with MLD values in the two groups.

A limitation of the study was selection bias, as it did not include the normal patients.

CONCLUSIONS

Our observations suggest that CXR in COPD patients is suggestive of hyperinflation. The CXR alone may not be an accurate method to label emphysema and more importantly, criteria to define hyperinflation/ emphysema in Indian patients with COPD varies from those of western standards. Further studies should be done to find out standard objective criteria of defining hyperinflation/emphysema on CXRs among Indian patients. The CT remains the best radiological method of assessing emphysema. Decreasing mean lung densities is an indicator of parenchymal destruction and can be easily and reliably measured with a simple technique. CT also helps in picking other findings not seen on CXR like bullae, bronchiectasis, etc.

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