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PULMONARY HYPERTENSION IN PULMONARY TUBERCULOSIS PATIENTS

General Medicine

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ABSTRACT

Introduction: Right heart failure is not an unusual finding in patients of Pulmonary TB, especially in a high burden country like India. These patients usually have a grave prognosis. It is essential to screen patients of pulmonary TB for Pulmonary hypertension as early intervention will improve chances of survival.

Aim and objectives: To assess the prevalence of pulmonary hypertension in patients of active pulmonary tuberculosis and its effect on physiological impairment, radiological abnormalities and echocardiographic parameters.

Material and methods: The study was conducted in the department of Medicine, Maharani Laxmi Bai Medical College, Jhansi, (UP) on the 150 patients of pulmonary tuberculosis. Ethical approval for the study was obtained from the ethical committee of the hospital and all patients gave informed consent to take part in the study.

Results: In our study out of 150 patients, the majority of patients were males-105 (70%), rest were female i.e. 45 (30%). According to found data majority of patients were found in age group of 31-50 yrs i.e. 65 (43.33%) followed by age group 51-80 i.e. 64 (42.67%) and minimum patients were found in age group 10-30 yrs i.e. 21 (14%) out of 150 patients. Mean±SD of different age groups in all 150 patients 10-30 yrs, 31-50 yrs and 51-80 yrs are 26.24±4.57, 41.58±4.83 and 68.75±4.50 respectively. 7 patients are having MDR, out of these patients, 4 (7.27%) patients having pulmonary hypertension in total 55 PH patients. P-values of this relation is 0.0379, i.e. statistically significant. Patients found SpO2 < 95% i.e. 36 (64.45%) and rest were 19 (34.55%). P-value is 0.0001, i.e. statistically highly significant.

Conclusion: From the observation, it appears that the "tuberculosis associated PH" as described by us is a distinct entity. Tuberculosis may have a causal association with PH and history of pulmonary tuberculosis, therefore, should be sought in all cases of PH, especially in the developing world. History of smoking apparently makes two distinct phenotypes in these patients as (a) COPD phenotype, and (b) interstitial lung disease phenotype; the later looks worse as per the PA pressure and the health status.

KEYWORDS

Tuberculosis Pulmonary hypertension Echocardiography

INTRODUCTION

Tuberculosis is a common and often deadly infectious disease caused by various strains of mycobacteria, usually Mycobacterium tuberculosis in humans (Kumar Vinay *et al*., 2007). Tuberculosis usually attacks the lungs but can also affect other parts of the body. It is spread through the air when people who have the disease cough, sneeze, or spit (Konstantinos, A. *et al*., 2010).

Pulmonary tuberculosis (TB) continues to be a major health problem worldwide. In spite of effective chemotherapy, excess morbidity and mortality are attributed to TB. Because treatment success in pulmonary TB has been defined as mycobacteriological response, little attention has been paid to the related chronic disabilities in those who survived the disease. Despite successful treatment, a significant permanent damage of lung function has been reported in more than 50% of pulmonary TB patients. They may be obstructive or restrictive and lead to gas exchange abnormalities and development of pulmonary hypertension.

Pulmonary tuberculosis continues to be a major global health problem causing significant morbidity and mortality in spite of modern and effective chemotherapy (World Health Organization, Global tuberculosis control, 2009).

If properly treated, tuberculosis caused by drug-susceptible strains is curable in virtually all cases. If untreated, the disease may be fatal within 5 years in 50–65% of cases ((Marioc. Raviglione *et al*., 2005)

AIMS AND OBJECTIVES

The aim and objectives of the study is to assess the prevalence of pulmonary hypertension in patients of active pulmonary tuberculosis and its effect on physiological impairment, radiological abnormalities and echocardiographic parameters.

MATERIALS AND METHODS

The study was conducted in the department of Medicine, Maharani Laxmi Bai Medical College, Jhansi, (UP) on the 150 patients of pulmonary tuberculosis. Ethical approval for the study was obtained from the ethical committee of the hospital and all patients gave informed consent to take part in the study.

Inclusion criteria:

All Patients with pulmonary tuberculosis diagnosed on basis of positive sputum smear /chest x-ray test as per RNTCP guidelines.

Exclusion criteria:

- Patients Age < 10 years and> 80 years.
- Primary lung pathologies
- All primary cardiac diseases
- Occupational lung diseases
- Malignant lung diseases

Chest x-ray findings:

The chest x-rays was analyzed by measuring the Cardiothoracic (CT) ratio, along with the widest diameter of the right descending pulmonary artery. Evidence of pulmonary hypertension was taken if right descending pulmonary artery width was >16mm. And also extent of parenchymal involvement of pulmonary TB is noted in the form lesions like lobar Collapse, fibrosis, cavitory lesion, bronchiectasis etc.

ECG findings

ECG was used to detect and exclude patients with Ischemic Heart Diseases (IHD). A 12 lead ECG was recorded in all the patients. The following ECG signs reflecting chronic cor- pulmonale were recorded: 1) P wave axis of +90 or more- right axis deviation, 2) P pulmonale, 3) right bundle branch block (RBBB), 4)RVH defined by one of following pattern, a) Q/R ratio in aVR >3, b) R/S ratio in V1>1.

Echo findings:

The Echocardiography was done in the department of Medicine, MLB Medical College, Jhansi on Echocardiographic machine Alpha-e. Make by Hitachi. The machine has following specifications:

Scanning methods:

- Electronic sector scan

- Electronic convex scanning
- Electronic linear scanning

Operation methods
- B Mode
- M Mode
- D mode (PW and CW modes) Flow mode
- Power flow mode, directional power flow mode Eflow mode, directional Eflow mode

PH was classified into mild, moderate and severe categsory as sPAP 30-50, 50-70, >70mmHg, respectively (MPAP) =0.61 PASP +2 mmHg and putting value of 25-35, 35-45, and >45 mmHg of MPAP for mild, moderate, and severe PH, respectively).

Right ventricle dimension was measured by M-mode echocardiography, and right ventricular dilation or COR-P was said to be present when it exceeded the normal range of 0.9-2.6 ern. Right ventricle contractility was also noted, and right ventricular systolic dysfunction was said to be present when it was hypo kinetic.
- A standard 4AC view is best to assess RV size compared with that of the LV.
- Mildly enlarged: RV is enlarged but <LV.
- Moderately enlarged: RV=LV
- Severely enlarged: RV>LV; apex of heart comprised ofRV.
- Diameter in diastole 4.2cm, >3.gcm at the mid level, and longitudinal dimension >8.6cm indicates RV dilation.
- As RV enlarges, it assumes more of spherical shape and can impair LV output.
- Measured in the PSAX view with focus on the RVOT and pulmonic valve.
- RVOT at the level of the pulmonic valve insertion is the distal diameter; measured at end diastole.
- PLAX RVOT proximal diameter >3.3cm indicated enlargement. P5AX RVOT distal diameter >2.9cm indicated enlargement.
- TR jet duration (continuous wave Doppler) and RVOT jet duration (pulsed wave Doppler) are recorded. The duration of TR is holosystolic and includes both isovolumic relaxation and contraction. RVOT ET only includes active ejection. Thus, the difference between the TR jet duration and RVOT jet duration is the isovolumic periods.

MPI = (Isovulumic contraction time (IVCT) + isovolumic relaxation time (IV /RT)/ET).

However,
ICVT + IVRT =
TR time - RVOT ET. MPI also is given as TR time - RVOT E/RVOT ET.

Tissue Doppler : IVCT, IVRT and ET are measured from tissue Doppler velocity of the lateral tricuspid annulus (TA). This technique avoids errors related to heart rate variability. RIMP is Falsely low with elevated RA pressures, which decrease the IVRT. 5' is a measure of RV systolic function and is measured by tissue Doppler at the lateral TA. 5' <10cm/sec indicates RV dysfunction.

M- mode findings:
As RV systolic function primarily relies on longitudinal myocardial shortening measurement of tricuspid annular plane systolic excursion (TAP5E) can be used.

In the *A4C* view, an M mode cursor is oriented to the junction of the TV plane with the RV free wall. T APSE is the difference in the displacement of the RV base during diastole and systole. Abnormal excursion is <1.6cm (low sensitivity but high specificity).

MPAP can be estimated using the following formulae:
MPAP = 1/3 (PASP) + 2/3(PAEDP) MPAP 90-(O.62ˣAT)
MPAP = 4x (peak velocity of PR jet)2 + RA pressure PVR = [(TRV)/VTIRvoT)x10+0.16

Where TRV, TR velocity; VTlrv of RVOT VTI

Pulmonary Hemodynamics:
PASP and pulmonary artery end diastolic pressure (PAEDP) can be estimated using the modified Bernoulli equation, which calculates the pressure difference between two chambers of the heart using the velocity of a jet between them.

LIP (measured in mmHg) - 4xV² (measured in m/sec) PASP = 4x (peak velocity of TR jet)2 + mean RA pressure

PAEDP = 4x (end velocity of PR jet)2+ RA pressure

The data was collected from the patients noted on predefined proforma regarding the detailed clinical history, clinical examination of the patients and relevant investigation. Patients was assigned a case number, and Studies that assessed the impact of treated PTB as a cause of disability ha e focused on impairment of lung function. These studies have shown significant residual lung function impairment in more than 50% of treated PTB patients and both obstructive and restrictive ventilatory defects have been described. It is known that persisting physiological impairment leads to gas exchange abnormalities and development of pulmonary hypertension which is a cause of severe disability and reduced longevity. However, few studies described pulmonary hypertension in treated PTB patients and most of the available information is from the prechemotherapy era.

We therefore conduct the study to investigate the presence of pulmonary hypertension in patients who is suffering from pulmonary tuberculosis.

RESULTS

Table-4.5: Sex wise distribution of severity of pulmonary hypertension.

	Mild	Moderate	Severe
Male (44)	31 (70.45%)	5 (11.36%)	8 (18.18%)
Female (11)	6 (54.55%)	0	5 (45.45%)
Total (55)	37	5	13

According to present data, severity based distribution of pulmonary hypertension in Mild, Moderate, and severity category is 31 (70.45%), 5 (11.36%) and 8 (18.18%) respectively in male and rest in female i.e. 6 (54.55%), 0 and 5 (45.45%) respectively.

Table-4.6: Sex wise distribution of severity of pulmonary hypertension (meanSD).

Sex (n=55)	Mild	Moderate	Severe
Male (44)	36.801.83	61.47.13	80.623.25
Female (11)	36.830.75	0	81.41.14
P-value	0.9580	0.0001	0.4392

According to present data, the meanSD in severity based distribution of pulmonary hypertension in Mild, Moderate, and Severity category is 36.801.83, 61.47.13 and 80.623.25 respectively in male and rest in female i.e. 36.830.75, 0 and 81.41.14 respectively. P-value of Mild, Moderate and Severe PH is 0.9580, 0.0001 and 0.4392 respectively.

Table-4.7: Relationship between duration of symptom of cough with pulmonary tuberculosis.

Duration of cough with sputum	No. of pulmonary tuberculosis patients	Percentage
< 30 days	61	40.67%
30 – 180 days	76	50.67%
181-365 days	10	6.67%
>365 days	3	2.00%
Total	150	100%

According to found data majority of patients were found in duration group of 30-180 days is 76 (50.67%) followed by <30 days i.e. 61 (40.67%) and minimum patients were found in duration group of >365 days i.e. 3(2%) out of 150 tuberculosis pulmonary patients.

Table-4.8: Relationship between duration of symptom of cough with sputum and PH.

Duration of cough with sputum (n=150)	PH	%	No PH	%
< 30 days (61)	22	40.00%	39	41.05%
30 – 180 days (76)	26	47.27%	50	52.63%
181-365 days (10)	7	12.73%	3	3.16%
>365 days (3)	0	0.00%	3	3.16%
Total	55	100%	95	100%

According to found data majority of patients were found in duration group of 30 – 180 DAYS i.e. 26 (47.27%) followed by <30 days 22 (40%). 7 (12.73%) patients were found in 181-365 DAYS group, while >365 DAYS having no patients.

Table-4.9: Presence of CT- Scan Finding In Total PH patients

CT findings		PH patients (55)		Non-PH patients (95)		P-value
		No	%	No	%	
Fibrosis	Yes	48	87.27%	77	81.05%	0.324
	No	7	12.73%	18	18.95%	
Bronchiectasis	Yes	10	18.18%	3	3.16%	0.001
	No	45	81.82%	92	96.84%	
Consolidation	Yes	15	27.27%	13	13.68%	0.039
	No	40	72.73%	82	86.32%	
Collapse	Yes	3	5.45%	2	2.11%	0.270
	No	52	94.55%	93	97.89%	
Cavity	Yes	43	78.18%	72	75.79%	0.739
	No	12	21.82%	23	24.21%	

According to found result of CT finding, in the total pulmonary hypertension (N=55), maximum number of patients having Fibrosis is 48 (87.27%) followed by Cavity is 43 (78.18%) and minimum patients having Collapse is 3 (5.45%). Most of the patients having both Fibrosis and cavity in CT scan finding. The p-value with comparison of PH and NON-PH for CT scan in different variables, Fibrosis, Bronchiectasis, Consolidation, Collapse and Cavity are 0.324, 0.001, 0.039, 0.270 and 0.739 respectively.

Table-4.10: Distribution of ECG characteristics of PTB patients according to PH.

ECG Changes	PH (n=55).	
	NO.	%
P pulmonale	37	67.27%
RBBB	3	5.45%
RVH	34	61.82%
RT axis daviation	28	50.91%

According to above table, ECG finding in PH (55) patients, maximum patients having P-Pulmonale is 37 (67.27%) followed by RVH is 34 (61.82%) and only 3 (5.45%) patients having RBBB. Most of the patients having both P-Pulmonale and RVH in ECG finding.

Table-4.11: Systolic pulmonary arterial pressure in total patients.

sPAP	No. of Patients	Percentage	MeanSD
PH (30)	55	36.67%	49.4719.19
No PH (<30)	95	63.33%	18.464.04
TOTAL	150	100%	

During Echocardiographic evaluation we found majority of patients having < 30 sPAP i.e. 95 (63.33%) out of 150 TB patients and rest of 30 sPAP i.e. 55 (36.67%) patients. The two-tailed P value is less than 0.0001, by conventional criteria; this difference is considered to be extremely statistically significant.

Table-4.12: Severity of pulmonary hypertension on the basis of systolic pulmonary arterial pressure (sPAP).

sPAP	PH	Percent	Mean SD
30-50 (Mild)	37	67.27%	36.817.13
51-70 (Moderate)	5	9.09%	61.47.13
> 70 (Severe)	13	23.64%	80.922.60
Total	**55**	**100**	

During Echocardiographic evaluation we found majority of patients were found in 30-50 (Mild) group i.e. 37 (67.27%) followed by > 70 (Severe) i.e. 13 (23.64%) and minimum were found in 51-70 (Moderate) is 5 (9.09%). Their Mean SD is 36.817.13, 80.922.60 and 61.47.13 respectively.

Table-4.13: Relationship between severity of PH on the basis of RV enlargement.

RV enlargement	PH	Percent	Mean SD
Mild	37	67.27%	36.817.13
Moderate	5	9.09%	61.47.13
Severe	13	23.64%	80.922.60
TOTAL	55	100	

During Echocardiographic evaluation we found majority of patients were found in Mild PH group i.e. 37 (67.27%) followed by Severe PH i.e. 13 (23.64%) and minimum were found in Moderate PH is 5 (9.09%). Their Mean SD is 36.817.13, 80.922.60 and 61.47.13 respectively.

Table-4.14: Relationship between smoking and pulmonary hypertension.

Smoking Habits	PH (n=55)	%	Non PH (n=95)	%
Yes	39	70.91%	51	53.68%
No	16	29.09%	44	46.32%
Total	55		95	100
p-value	0.0379			

Out of total 150 patients, 55 having pulmonary hypertension, out of these, majority of cases were having smoking habit i.e. 39 (70.91%) and rest 16 (29.09%) not having smoking habits. P-values of this relation is 0.0379, i.e. statistically significant.

Table-4.15: Relationship between MDR and Pulmonary Hypertension.

MDR	PH (n=55)	%	Non PH (n=95)	%
Yes	4	7.27%	3	3.16%
No	51	92.73%	92	96.84%
Total	55	100%	95	100%
p-value	0.0379			

Out of total 150 patients, 7 patients are having MDR, out of these patients, 4 (7.27%) patients having pulmonary hypertension in total 55 PH patients. P-values of this relation is 0.0379, i.e. statistically significant.

Table-4.16: Distribution of SpO2 of PTB patients according to Pulmonary Hypertension.

SpO2	PH (n=55)	%	Non PH (n=95)	%
≥95%	19	34.55%	57	61.05%
< 95%	36	64.45%	36	38.95%
Total	55	100%	95	100%
Mean SD	92.213.23		94.854.25	
p-value	0.0001			

Out of total 55 PH patients, majority of patients found SpO_2 < 95% i.e. 36 (64.45%) and rest were 19 (34.55%). P-value is 0.0001, i.e. statistically highly significant.

DISCUSSION

The study was conducted in the department of Medicine, MLB Medical College, Jhansi, (UP) on the 150 patients of pulmonary tuberculosis.

In our study, out of 150 patients, the majority of patients were males-105 (70%), rest were female i.e. 45 (30%). in the total 150 patients, mean ageSD are 47.7513.85. Maximum number of PH patients were found in age group of 31-50 yrs i.e. 26 (47.27%) followed by age group 51-80 i.e. 22 (40%) and minimum patients were found in age group 10-30 yrs i.e. 7 (12.73%) out of 55 and maximum were males i.e. 44 (80%) while rest were females i.e. 11 (20%).

Similar result was found in a study of 728 pulmonary TB patients, 104 were found to have Pulmonary Hypertension. 28 (27%) were Newly Diagnosed TB cases while 76 (73%) patients had previous history of anti TB Treatment suggesting significant association of Pulmonary Hypertension with previous history of pulmonary TB. (**Mani Tiwari *et al.*, (2017).**

In another study conducted by **Muhammed Waheeb Al.Obaidy *et al*., (2018)** on 50 active pulmonary tuberculosis (PTB) patients were included in this study with mean age of 40.4±19 years; Males were more than females with the male to female ratio as 1.08:1.

In another study 40 patients having PH were evaluated with a history of treatment of tuberculosis in which it was found that 26 were males and 14 females; mean age was 57.9±13.55 (Parthasarathi Bhattacharyya et al., 2016).

In a study of 101 patients, dyspnea was present in 58/101 (57.4%) while 77/101 (76.2%) patients had cough and a total of 38/58 (65.5%)

patients with dyspnea had this symptom for more than 6 months duration (Ananya Panda **et al., 2016).**

According to our data majority of patients were found in duration group of 30-180 DAYS i.e. 26 (47.27%) followed by <30 days 22 (40%). 7 (12.73%) patients were found in 181-365 DAYS group, while >365 DAYS having no patients.

In our study the ECG finding in PH (55) patients, maximum patients having P-Pulmonale is 37 (67.27%) followed by RVH is 34 (61.82%) and only 3 (5.45%) patients having RBBB. Most of the patients having both P-Pulmonale and RVH in ECG finding.

A study conducted by ***Majid Marjani et al.,*** **(2014),** out of 777 new cases of pulmonary tuberculosis, 74 (9.5%) had systolic pulmonary arterial pressure ≥35 mm Hg. Ten of them (13.5%) died during treatment compared to 5% of cases with pulmonary arterial pressure less than 35 mm Hg ($p = 0.007$).

In another study 50 patients evaluated by transthoracic Doppler echocardiography including estimation of pulmonary artery systolic pressure (PASP) and tricuspid annular plane systolic excursion (TAPSE). Resulted that, among 50 active pulmonary tuberculosis (PTB) patients, 4 had pulmonary artery systolic pressure (PASP) ≥40 mm Hg, 2 of them had right ventricular dilation and TAPSE (**Muhammed Waheeb *et al.*, (2018).**

Ala Eldin *et al.*, (2011) revealed that during Echocardiographic evaluation we found majority of patients having < 30 sPAP i.e. 95 (63.33%) out of 150 Tb patients and rest of >30 sPAP i.e. 55 (36.67%) patients. While studying the relationship between severity on the basis of systolic pulmonary arterial pressure (sPAP) and PH by echocardiographic evaluation we found majority of patients were found in 30-50 (Mild) group i.e. 37 (67.27%) followed by >70 (severe) i.e. 13 (23.64%) and minimum were found in 51-70 (moderate) is 5 (9.09%). In a study on of the 14 patients, pulmonary artery systolic pressure was estimated echocardiographically. Most of the patients had moderate PHT (PASP 51-80 mm/Hg) whereas only one patient had severe PHT (PASP more than 80 mm/Hg) (**Ala Eldin h. Ahmad *et al.*,2011**).

Muhammed Waheeb Al.Obaidy *et al*., (2018) conducted a study on 50 active pulmonary tuberculosis (PTB) patients, the ECG findings of PTB patients included the mean heart rate of 89.4±19.6 b/m, 40% of PTB patients had sinus tachycardia. No PTB patient had P. pulmonale and RVstrain. Only one PTB patient had RAD and one PTB patient had RBBB. The echocardiography findings of PTB patients included the followings; four PTB patients had raised PASP, so Pulmonary hypertension (PHT) was found among 8% of PTB patients. Two PTB patients had mild PHT, two patients had moderate PHT and no patient had severe PHT.

In our study found that, during Echocardiographic evaluation we found majority of patients having < 30 sPAP i.e. 95 (63.33%) out of 150 TB patients and rest of 30 sPAP i.e. 55 (36.67%) patients. The two-tailed P value is less than 0.0001, by conventional criteria; this difference is considered to be extremely statistically significant. During Echocardiographic evaluation we found majority of patients were found in 30-50 (Mild) group i.e. 37 (67.27%) followed by > 70 (Severe) i.e. 13 (23.64%) and minimum were found in 51-70 (Moderate) is 5 (9.09%). Their Mean SD is 36.817.13, 80.922.60 and 61.47.13 respectively.

A study conducted by **Parthasarathi Bhattacharyya** *et al.,* (2016). They resulted that the total of 40 patients (21 smokers and 19 nonsmokers) were found to have PH with history of pulmonary tuberculosis. The two groups were similar radiologically including the extent of fibrosis. The nonsmoker group had lower age range (52.16 ± 14.81 vs. 63.1 ± 10.05, P = 0.01), worse chronic obstructive pulmonary disease (COPD) assessment test score (16.11 ± 6.24 vs. 13.9 ± 5.6, P = 0.25) and higher pulmonary artery (PA) pressure (46.39 ± 7.44 vs. 44.55 ± 8.04, P = 0.46) compared to the smokers.

In a study on 195 such patients, approximately 47% of the patients were ex- or current smokers (Yong Suk Jo ***et al.,*** **2017)**. In another study 777 pulmonary tuberculosis patients were studied in whom 74 developed PH and out of them 31.1% were smokers.

Another study included 84 patients with a mean age of 44.9 years, predominantly male (86.9%6) and rural (61.9%). Investigation revealed that smoking status was 23.81% nonsmoking, 22.62% former smokers and 53.57% smokers. 64.29% of patients were new cases of pulmonary TB, 15.47% relapse and 20.24% patients with chronic pulmonary TB. Obstructive and mixed ventilatory defects are significantly associated with age over 40 years, male gender, smoking, category of chronic case of TB and radiological lung lesions extension **(**Apostu M, Mihăescu T**. *et al., (*2013).**

In our study, out of total 150 patients, 55 having pulmonary hypertension, out of these, majority of cases were having smoking habit i.e. 39 (70.91%) and rest 16 (29.09%) not having smoking habits.

Wei Yan *et al*., (2015). Resulted that, one hundred and nineteen IPF patients were evaluated for sPAP by echocardiography and were diagnosed as: PH likely ($n = 28$, 23.5%), PH possible ($n = 20$, 16.8%), PH unlikely ($n = 71$, 59.7%), respectively. The incidence of PH in IPF was 23.5% (28/119) when only likely PH was definite and the incidence of PH in IPF was 40.3% (48/119) when likely PH and possible PH were taken together..

According to our study in the total pulmonary hypertension patients (N=55), maximum number of patients having Fibrosis is 48 (87.27%) followed by Cavity is 43 (78.18%) and minimum patients having Collapse is 3 (5.45%). Most of the patients having both Fibrosis and cavity in CT scan finding. In a study conducted on 14 patients of pulmonary hypertension all patients had abnormal chest radiographs.

CONCLUSION

From the observation, it appears that the "tuberculosis associated PH" as described by us is a distinct entity. Tuberculosis may have a causal association with PH and history of pulmonary tuberculosis, therefore, should be sought in all cases of PH, especially in the developing world. History of smoking apparently makes two distinct phenotypes in these patients as (a) COPD phenotype, and (b) interstitial lung disease phenotype; the later looks worse as per the PA pressure and the health status. This association of tuberculosis and PH needs further elaboration and investigation.

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