ORIGINAL ARTICLE

Impact of pulmonary hypertension on mortality in progressive massive fibrosis

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ABSTRACT

Background and aim: The aim of this study was to investigate the factors affecting the development of pulmonary hypertension (PH) in patients with progressive massive fibrosis (PMF) and to determine the relationship between PH development and life expectancy.

Methods: In this retrospective study, 181 patients with PMF were recruited over a 9-year period and 96 were eligible for analysis. We used echocardiography (ECHO) findings to estimate the likelihood of developing PH. We used Bernoulli's equation with tricuspid regurgitation velocity measurement and calculated systolic pulmonary artery pressure (sPAP) by adding the estimated right atrial pressure. We accepted sPAP values of 37 and 50 mm Hg as criteria for moderate and high probability PH.

Results: The prevalence of moderate or high probability PH (PH group) was 29.1% in patients with PMF. Older age (OR:1.059, p=0.036) and presence of C opacity (OR:4.607, p=0.024) were found to be risk factors for PH in patients with PMF. The survival rate (39.2%) and mean survival time (65.20±9.94 months) were significantly lower in the PH group compared to the non-PH group (p=0.002). PH development was primarily associated with fibrotic disease burden rather than coexisting airflow obstruction.

Conclusions: The development of PH and the increase in the degree of PH have a negative effect on the mean survival time. Preventing the development of PMF, which has a poor prognosis, by taking necessary precautions is the most effective option in treatment.

Key words: Pneumoconiosis, pulmonary, fibrosis, hypertension, survival

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Introduction

Pneumoconiosis is a disease caused by the accumulation of inorganic dust, smoke and fibres in the lung, causing a fibrotic tissue reaction (1). Silicosis, coal workers' pneumoconiosis, asbestosis and mixed dust pneumoconiosis are the most well-known pneumoconiosis (2). Pneumoconiosis is a potential cause of disability and causes a significant socioeconomic burden, especially in developing countries (3). It can cause complications such as chronic obstructive pulmonary disease (COPD), pneumothorax, respiratory infections such as tuberculosis and pulmonary hypertension (PH) (4). Pneumoconiosis is divided into 2 groups as simple and complicated according to radiological appearance. The presence of round or linear opacities less than 1 cm on the chest radiograph is simple pneumoconiosis. The International Labour Organization Classification/International Classification of Radiographs of Pneumoconioses (ILO/ICRP) classifies the size of round or linear opacities in 3 categories. Diametres/widths up to 1.5 mm, diametres/widths exceeding 1.5 mm and up to 3 mm, and diametres/widths exceeding 3 mm and up to 10 mm. Profusion of small opacities refers to the density of small opacities in the affected areas of the lung. The profusion category is based on comparison with standard radiographs. 4 categories and 12 subcategories were defined. Complicated pneumoconiosis (progressive massive fibrosis) is the appearance of opacities larger than 1 cm in size in combination with small opacities on chest radiography (5,6). Progressive massive fibrosis (PMF) is divided into 3 categories: category A (one or more opacities greater than 10 mm in diameter but less than 50 mm in diameter), category B (one or more opacities greater than 50 mm in diameter but not exceeding the right upper zone), and category C (one or more opacities with a diameter exceeding the right upper zone) (5). Silicosis is caused by inhalation of the crystalline form of silica (silicon dioxide), a major constituent of rock and sand (7). Occupations associated with an increased risk of silicosis include foundry, dental technician, mining, tunnelling, marble work, artificial stone work, ceramic work, sandblasting and construction work (4). There are publications showing that PH develops in a significant proportion of patients diagnosed with silicosis and significantly reduces survival. It is thought that the development of PH is caused by repetitive damage to the pulmonary vascular structure. Proliferative vasculopathy develops as a result of vasoconstriction, cellular hyperplasia, fibrosis and thrombosis in small pulmonary arteries and arterioles. PH leads to right heart failure in the absence of treatment (8). The aim of our study was to investigate the factors affecting the development of PH in patients with PMF, to determine the relationship between the development of PH and life expectancy and to contribute to the data in Türkiye.

Methods

Database and study population

The medical records of patients with pneumoconiosis who were followed up as outpatients or inpatients in the Occupational Diseases Clinic between January 2014 and December 2022 were analysed. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee. The diagnosis of pneumoconiosis was based on a history of occupational inorganic dust exposure, the presence of radiological findings compatible with pneumoconiosis and the exclusion of other diagnoses. Those diagnosed with PMF according to the International Labour Organization (ILO) radiographic classification of pneumoconiosis were included in the study. Exclusion criteria were lack of demographic data and absence of echocardiography (ECHO). Spirometry was performed using the Zan 100 flow-sensitive spirometry device (ZAN Messgerate GmbH, Oberthulba, Germany). The spirometer was calibrated daily, with measurements of temperature and humidity used for calibration. The spirometry results were analyzed based on the acceptability and reproducibility criteria presented in the ATS/European Respiratory Society statement updating the standardization of spirometry. The patients' spirometry measurements were evaluated based on the percentage of the reference values. Static lung volumes, forced expiratory volume in the first second (% predicted FEV1), forced vital

capacity(% predicted FVC) and the FEV1/FVC ratio were measured. Right heart catheterisation (RHC) is the gold standard for pulmonary hypertension (PH) diagnosis; however, echocardiography (ECHO) is widely used due to its non-invasive nature and strong correlation with haemodynamic measurements. ECHO provides comprehensive information on cardiac structure, valvular abnormalities, and haemodynamic parameters. Tricuspid regurgitation velocity (TRV) was measured to estimate systolic pulmonary artery pressure (sPAP) using the Bernoulli equation ($\Delta P = 4 \times V^2$), with estimated right atrial pressure added to calculate sPAP (9-14).

Echocardiographic assessment of LA, LV and diastolic function

All included patients underwent comprehensive echocardiographic evaluation, including left atrial (LA) diameter, left ventricular ejection fraction (LVEF), mitral inflow velocities (E/A ratio), tissue Doppler e′, E/e′ ratio, and assessment for valvular regurgitation. All patients exhibited normal LA size, preserved LV systolic function, and no clinically significant diastolic dysfunction. These findings effectively excluded Group 2 PH due to left-heart disease. Patients without a reliably measurable TRV signal were excluded prior to analysis.

Right heart catheterisation was not routinely performed in this cohort, as none of the patients were evaluated in a transplant centre or specialised pulmonary hypertension unit. Therefore, PH assessment was based exclusively on echocardiographic probability criteria according to ESC/ERS 2022 guidelines.

ESC/ERS 2022 PH probability criteria

- PH is unlikely if TRV ≤2.8 m/s, sPAP ≤36 mmHg and no additional PH findings are present.
- PH is possible if TRV ≤2.8 m/s with additional PH findings, or if TRV 2.9–3.4 m/s with sPAP 37–50 mmHg.
- PH is highly probable if TRV >3.4 m/s and sPAP >50 mmHg with or without additional PH findings (9,15).

Patients were assigned to three groups

1. Low probability PH: sPAP <37 mmHg
2. Moderate probability PH: sPAP 37–50 mmHg
3. High probability PH: sPAP >50 mmHg

Statistical analysis

Statistical analyses were performed using SPSS Statistics V.23 (IBM). The normal distribution of the data was evaluated by Kolmogorov-Smirnov and Shapiro-Wilk tests. Descriptive statistics were given as mean, minimum and maximum for continuous variables and number and percentage for categorical variables. In the comparison of two independent groups in continuous variables, independent sample t test was used for normally distributed data and Mann Whitney U test was used for data that did not conform to normal distribution. Categorical data were analysed by Pearson chi-square and Fisher's Exact test. The effect of independent risk factors on the prediction of PH risk was analysed by logistic regression analysis. Kaplan-Meier analysis and Log rank test were used to calculate the survival of the patients. The relationship between the risk factors and survival was evaluated by univariate and multivariate Cox regression analysis. Statistical significance was determined as $p<0.05$.

Results

Demographic findings

A total of 181 patients diagnosed with PMF were included in the study and 85 of them were excluded according to the exclusion criteria. Patients with alternative diagnoses that could independently cause PH-such as vasculopathy, lymphadenopathy (e.g., sarcoidosis) were excluded during the selection process. In addition, patients in whom tricuspid regurgitation velocity (TRV) could not be reliably measured on echocardiography were excluded, as PH probability assessment in this study was based on TRV-derived systolic pulmonary artery pressure estimation. A total of 96 patients who underwent ECHO were included

in the analysis. All patients were male and the mean age was 56.99±13.44 years. The mean duration of exposure to inorganic dust was 20.89±10.96 years. The mean smoking duration was 25.21±16.78 pack-years. The number of patients with comorbidities was 74 and the number of patients without any disease was 22. Chronic obstructive pulmonary disease (COPD) was present in 40 patients, asthma in 4, pulmonary tuberculosis in 18, hypertension in 18, coronary artery disease (CAD) in 21, diabetes mellitus in 12, and cancer in 7. 17 patients had comorbidities such as Parkinson's disease, benign prostatic hypertrophy, chronic renal failure and epilepsy. 91 patients had spirometry. In spirometry evaluation, FEV1/FVC ratio was found to be below 70% in 46 patients (47.9%). The mean %FEV1 was 58.51±21.66, %FVC 66.25±19.52 and FEV1/FVC ratio 69.27±13.29. The occupations of the patients were mining (n=30), dental technician (n=14), foundry worker (n=13), quarry worker (n=10), ceramic worker (n=10), sandblasting (n=7), tunnel worker (n=3), construction worker (n=3), glass worker (n=3), welder (n=1), marble worker (n=1) and artificial stone worker (n=1). Progressive massive fibrosis (PMF) was divided into 3 categories. There were 36 patients with opacity A, 27 patients with opacity B and 33 patients with opacity C. The 96 patients with ECHO were divided into 3 groups as low probability (sPAP<37 mmHg), moderate probability (sPAP≥37 mmHg and sPAP≤50 mmHg) and high probability (sPAP>50 mmHg) PH. There were 68 patients with low probability of PH (no PH), 15 patients with moderate probability of PH and 13 patients with high probability of PH on ECHO. Demographic characteristics of the patients are shown in Table 1.

Risk factors of pulmonary hypertension

The relationship between demographic characteristics of the patients and PH status/groups was analysed. Among those included in the study, the frequency of being in the moderate and high probability PH group was found to be statistically significantly higher in those with a diagnosis of CAD (p=0.016). Among the patients included in the study, the ages of those in the moderate probability PH group were statistically significantly higher than those in the non-PH group (p=0.008). FEV1 and FEV1/FVC values of the patients in the moderate probability PH group were significantly lower than those in the Non-PH group (p=0.015, p=0.006). The frequency of A opacity in patients in the non-PH group was statistically significantly higher than those in the high probability PH group (p=0.018). No statistical relationship was found between small opacity status and profusion scores and PH status/groups (p>0.05). The independent risk factors of age, FEV1/FVC, C opacity and presence of CAD were investigated by multiple logistic regression analysis in Table 2. In the study, a multivariate logistic regression analysis model was created with age, FEV1/FVC, presence of C opacity and presence of coronary artery disease, which were found to be statistically significantly associated with independent risk factors for the prediction of PH in univariate analyses. Older age (OR:1.059, p=0.036) and presence of C opacity (OR:4.607, p=0.024) were found to be risk factors for PH, while FEV1/FVC (OR:0.943, p=0.017) was found to be a protective factor. The model explained 29.2% of the total variance related to PH risk. None of the patients received pulmonary arterial hypertension–specific therapy. Management consisted of supportive treatment, including long-term oxygen therapy when indicated, bronchodilators, and treatment of comorbidities. Therefore, the impact of PH-specific treatment on outcomes could not be evaluated.

Survival analyses of PMF patients with pulmonary hypertension

Among the patients included in the study, the prevalence of the PH group (moderate and high probability PH) was 29.1% and the survival rate was 39.2%. The mean survival time of the PH group was 65.20±9.94 months, which was significantly lower than the non-PH group (101.71±6.80) (Log Rank test; p=0.002).

The mean survival times of the patients included in the study were calculated as 101.715 months in the low probability PH (Non-PH) group, 66.411 months in the moderate probability PH group and 51.762 months in the high probability PH group. There was a statistically significant difference between the groups (Log Rank test; p=0.002) (Figure 1).

Table 1. Demographic characteristics of the patients

		n (%)/Mean±SD
Gender (Male)		96 (100)
Age (years)		56.99±13.44
Inorganic Dust Exposure (years)		20.89±10.96
Smoking Duration (pack-years)		25.21±16.78
Never smoked		19 (19.8)
Ex-smoker		43 (44.8)
Current smoker		34 (35.4)
Spirometry		91 (94.8)
FEV1 (%)		58.51±21.66
FVC (%)		66.25±19.52
FEV1/FVC		69.27±13.29
Comorbidity	**Yes**	74 (77.08)
	No	22 (22.91)
Comorbidity	**COPD**	40 (54.05)
	Asthma	4 (5.40)
	Pulmonary tuberculosis	18 (24.32)
	Hypertension	18 (24.32)
	Coronary artery disease	21 (28.37)
	Diabetes mellitus	12 (16.21)
	Malignancy	7 (9.45)
	Other diseases[#]	17 (22.97)
ECHO	**Low probability PH (NonPH) (sPAP<37 mmHg)**	68 (70.83)
	Moderate probability PH (sPAP 37-50 mmHg)	15 (15.62)
	High probability PH sPAP>50 mmHg	13 (13.54)
Occupation	**Miner**	30 (31.25)
	Dental Technician	14 (14.58)
	Foundry worker	13 (13.54)
	Ceramic worker	10 (10.42)
	Quarry worker	10 (10.42)
	Sandblaster	7 (7.29)
	Other occupations[*]	12 (12.5)
PMF	**A Opacity**	36 (37.5)
	B Opacity	27 (28.12)
	C Opacity	33 (34.37)

[#] Parkinson's disease, benign prostatic hypertrophy, chronic renal failure, epilepsy
[*] Tunnel worker, glass worker, construction worker, marble worker, artificial stone worker, welder

When the 1- and 5-year survival rates of the patients according to the PH groups were analysed, it was found that the 5-year survival rate of the high probability PH group decreased to 35% (Table 3).

In the study, the effects of risk factors on survival in univariate and multivariate analyses were examined by cox regression analysis. In univariate analyses, a statistically significant association was found between mortality and high probability PH group, older age and amount of smoking (HR:4.104, p=0.001; HR:1.048, p=0.001; HR:1.035, p=0.004). A multivariate analysis model was designed with these variables. Multivariate analysis showed that high probabilty PH status and older age had a statistically significant effect on survival (HR:2.989 p=0.025; HR:1.054, p=0.005) (Table 4).

Table 2. Logistic regression analysis of independent risk factors and prediction of PH

	OR	95% CI	p value
Age (years)	1.059	1.004 to 1.117	**0.036**
FEV1/FVC ratio	0.943	0.899 to 0.980	**0.017**
C opacity	4.607	1.219 to 17.409	**0.024**
CAD	3.407	0.952 to 12.190	0.059

Discussion

Pulmonary hypertension due to pneumoconiosis is associated with high mortality and poor prognosis. Yu et al. found that the survival rate of the PH group was significantly lower than that of the non-PH group during a median follow-up period of 32.8 months in patients with PMF (16). In another study, the 5-year survival rate of PMF was 76.6% (17). In our study, 29.1% of patients with PMF developed PH. The 1- and 5-year survival rates of the patients according to the PH groups were analysed and it was found that the 5-year survival rate of the high probability PH group decreased to 35%. There was a decrease in the mean survival time from the low probability PH group to the high probability PH group and there was a statistical difference between the groups. Pathological studies support the mechanistic association between PMF severity and PH. In an autopsy study, progressive stenoses were observed in the pulmonary arteries within and adjacent to large opacities in the lungs of patients with PMF and right ventricular hypertrophy. It was observed that the lumen of the vessels was markedly narrowed and the structure of the vessels was disrupted. Increased size of the PMF was found to be risk factors for the development of PH (18). In a study conducted on coal workers, it was thought that

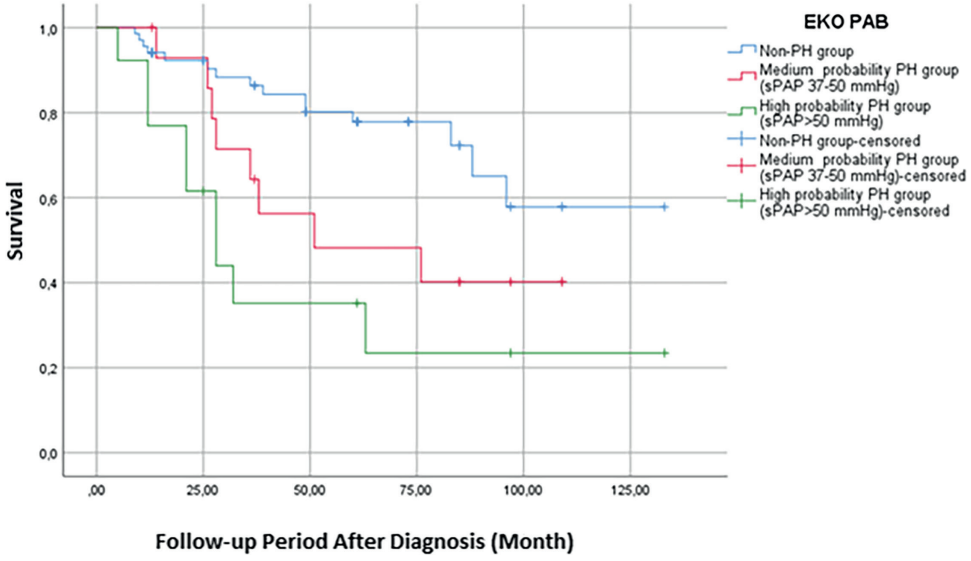

Figure 1. Kaplan-Meier survival curve of patients according to PH groups

Table 3. Survival rates of patients according to PH groups at 1 and 5 years

	1-year survival rate	5-year survival rate
Low probability PH group (sPAP<37 mmHg)	94%	77%
Moderate probability PH group (sPAP 37-50 mmHg)	92%	48%
High probability PH group (sPAP>50 mmHg)	76%	35%

Table 4. Effects of risk factors on survival by univariate and multivariate analyses

		Univariate Analysis		Multivariate Analysis	
		HR (%95 CI)	**p**	**HR (%95 CI)**	**p**
	Low probability PH group (Non-PH)	1.00		1.00	
PH groups	**Moderate probability PH group**	2.209 (0.934-5.228)	0.071	1.886 (0.702-5.068)	0.208
	High probability PH group	4.104 (1.747-9.222)	**0.001**	2.989 (1.150-7.770)	**0.025**
Age		1.048 (1.019-1.078)	**0.001**	1.054 (1.016-1.093)	**0.005**
Opacity	**A+B**	1.00			
	C	1.926 (0.961-3.861)	0.065		
Exposure duration		1.029 (0.997-1.063)	0.077		
FEV1/FVC		0.623 (0.217-1.793)	0.061		
Cigarettes (pack/year)		1.035 (1.011-1.059)	**0.004**	1.012 (0.989-1.037)	0.302
Comorbidity	**None**	1.00			
	Yes	1.648 (0.632-4.295)	0.307		

PH developed as a result of destruction of large areas of the pulmonary vascular bed as a result of complicated pneumoconiosis, suggesting that complicated pneumoconiosis alone may be associated with cor pulmonale. In addition, it has been reported that development of PH in simple pneumoconiosis is rare (19). There are studies showing that the size as well as the distribution of PMF has an effect on the development of PH. In one study, it was thought that the central distribution of PMF may compress the proximal pulmonary arteries, the larger the lesion area, the larger the area of the affected pulmonary arteries, and this may be associated with the development of PH in PMF (20). In our study, statistically significant associations were found in univariate analyses with age, FEV1/FVC, presence of C opacity and coronary artery disease, which were independent risk factors for the development of PH. Although COPD was present in 54% of our patients, it did not independently predict the development of pulmonary hypertension. Recent reviews emphasise that pulmonary hypertension arising in the context of fibrotic interstitial lung disease (ILD-PH) represents a distinct clinical phenotype, characterised by specific pathophysiological mechanisms and prognostic implications, which differ from the airflow obstruction– and hypoxia-driven processes typical of COPD-associated

PH (21,22). Notably, the FEV1/FVC ratio emerged as a protective factor in multivariate regression analysis, further supporting the notion that airflow limitation per se was not the primary determinant of PH in this cohort. Collectively, these findings suggest that pulmonary hypertension in PMF is predominantly driven by fibrotic disease burden, reflecting pulmonary vascular destruction and mechanical vascular compression characteristic of fibrosis-associated (ILD-PH) mechanisms rather than hypoxia-mediated COPD-related PH. Importantly, comprehensive echocardiographic evaluation demonstrated normal left atrial size, preserved left ventricular systolic function, and no evidence of significant diastolic dysfunction, effectively excluding Group 2 PH secondary to left-heart disease. Large epidemiological cohorts of pneumoconiosis patients—particularly those from China—have consistently shown that older age, advanced disease stage, and prolonged dust exposure are associated with poorer survival. This evidence is supported by a retrospective study of 13,812 patients in which higher diagnostic stage, older age at diagnosis, longer exposure duration, and employment in mining or certain public sectors were independently associated with increased mortality risk (23,24). Similar findings have also been reported by Dai et al. (25), who demonstrated that advancing age in pneumoconiosis patients is accompanied by disease progression, a higher frequency of complications, and reduced survival. In line with this established body of literature, our results likewise demonstrate that both older age and a high probability of pulmonary hypertension independently predict shorter mean survival. The present study has limitations, including its retrospective single-centre design, the lack of right heart catheterisation confirmation, and the absence of key non-invasive surrogate markers of pulmonary vascular disease (DLCO/KCO and derived indices such as FVC/DLCO or FEV1/DLCO). Functional assessment data (e.g., six-minute walk test) were not systematically available, and right ventricular structure/function parameters (TAPSE, TAPSE/sPAP, FAC, and right ventricular dilatation) were not routinely recorded, precluding correlation analyses with PH probability or outcomes. In addition, oxygen saturation measurements were incomplete. Finally, a proportion of PMF patients were excluded due to the absence of a measurable TRV signal, which may have introduced selection bias and limited the generalisability of our findings. Nevertheless, echocardiography-based PH probability assessment is supported by ESC/ERS guidelines and is widely used in large clinical cohorts. In conclusion, older age, coronary artery disease, lower FEV1 and FEV1/FVC ratios, and especially category C opacity increase the risk of PH in PMF. High-probability PH significantly reduces survival. Close follow-up using echocardiography and pulmonary function testing is essential for early recognition of PH. Prevention of PMF through occupational exposure control remains the most effective strategy, given the limited therapeutic options and high mortality associated with PH once it develops.

Conflict of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Declaration on the use of AI: AI (Artificial Intelligence) was not used in this study.

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