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Non-invasive risk stratification of pulmonary hypertension in idiopathic pulmonary fibrosis: a screening approach from a prospective observational study

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Abstract

Pulmonary hypertension (PH) is a major complication of idiopathic pulmonary fibrosis (IPF), but its detection remains challenging because right-heart catheterization is invasive and echocardiography has limited accuracy in advanced lung disease. We assessed the feasibility of a multiparametric non-invasive screening approach and its concordance with echocardiographic PH probability in patients with IPF.

In this prospective single-center observational study, 27 patients with multidisciplinary-confirmed IPF were enrolled from November 2024 to May 2025. Patients were classified as having low, intermediate, or high PH risk using the PH-ILD Detection Tool, incorporating clinical, functional, imaging, and biomarker variables. All patients underwent transthoracic echocardiography and were classified according to echocardiographic PH probability. No patient underwent right-heart catheterization.

The PH-ILD Detection Tool classified 14 patients as low risk, 5 as intermediate risk and 8 as high risk. Echocardiography indicated low PH probability in 14 patients, intermediate probability in 4, and high probability in 9. Thirteen of the 14 patients classified as low risk had a low echocardiographic probability. Higher echocardiographic PH probability was associated with greater dyspnea severity, NT-proBNP >300 ng/L, lower resting PaO_2 and lower nadir SpO_2.

The PH-ILD Detection Tool showed promising concordance with echocardiographic PH probability and may help prioritize patients with IPF for cardiovascular assessment. However, the small sample size and absence of right-heart catheterization preclude diagnostic validation, and the findings should be considered exploratory.

Key words: pulmonary circulation, echocardiography, natriuretic peptides, exercise test, risk assessment, heart catheterization**.**

Introduction

Pulmonary hypertension (PH) is a frequent and prognostically important complication of idiopathic pulmonary fibrosis (IPF). Its reported prevalence varies according to disease severity, haemodynamic definition and diagnostic method, ranging from approximately 8–15% at the time of IPF diagnosis to more than 60% in patients with advanced disease or those evaluated for lung transplantation. The development of PH is associated with worsening functional capacity, impaired quality of life and increased mortality [1-3].

Early identification of PH in patients with IPF is important for diagnostic planning, treatment optimisation and timely referral for lung transplantation. Right-heart catheterisation (RHC) remains the reference standard for diagnosis; however, its invasive nature limits its use as a universal screening procedure. Echocardiography, CT-derived pulmonary artery measurements, pulmonary function variables, exercise testing and natriuretic peptides may raise suspicion of pulmonary vascular involvement, but no single non-invasive test provides sufficient diagnostic accuracy in IPF [4,5].

The optimal strategy for selecting patients who require further cardiovascular assessment or RHC therefore remains uncertain, particularly in resource-limited settings.

We hypothesised that a composite approach integrating clinical, functional, imaging and biomarker variables could identify patients with a higher echocardiographic probability of PH more effectively than isolated screening parameters. This study therefore aimed to assess the feasibility of the PH-ILD Detection Tool in patients with IPF and to examine its concordance with echocardiographic PH probability.

Materials and Methods

Study design and participants

We conducted a prospective single-centre observational study from November 2024 to May 2025 involving 27 consecutive patients with a multidisciplinary diagnosis of idiopathic pulmonary fibrosis (IPF). Participants were recruited from the Department of Pneumology, Phthisiology and Allergology, Rouïba Public Hospital (University of Health Sciences, Algiers), a regional referral centre for interstitial lung diseases (ILDs) in Algeria. The study was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Committee.

Patient selection and the standardized investigation protocol were based on our previously published ILD cohorts [6,7].

The diagnosis of IPF was established by multidisciplinary discussion integrating clinical, radiological and functional findings according to international ATS/ERS/JRS/ALAT guidelines [8].

Non-invasive assessment

All patients underwent a standardized non-invasive assessment including high-resolution computed tomography (HRCT) to characterize fibrotic abnormalities and measure the main pulmonary artery diameter [9,10]; pulmonary function testing, including spirometry performed according to ATS/ERS recommendations using reference equations validated in the Algerian population [11,12]**,** arterial partial pressure of oxygen, and diffusing capacity of the lung for carbon monoxide (DLCO), whenever feasible [13]; six-minute walk testing (6MWT), including walking distance and nadir oxygen saturation (SpO_2) [14]; plasma N-terminal pro-brain natriuretic peptide (NT-proBNP) measurement [15]; and transthoracic echocardiography (TTE) to assess pulmonary hypertension (PH) probability according to the 2022 ESC/ERS Guidelines [16].

The PH-ILD Detection Tool proposed by Parikh et al. [17,18] was calculated for each patient using predefined clinical, physiological, imaging and biomarker variables. Patients were classified as having low, intermediate or high PH risk according to the original score thresholds.

Right-heart catheterization (RHC) was not performed in this study. Therefore, echocardiographic PH probability was used as the study comparator rather than as a haemodynamic diagnostic reference standard, consistent with previous non-invasive screening studies in ILD [19]. The non-invasive screening strategy was based on contemporary approaches to PH detection in ILD and the recognised need for earlier identification of pulmonary vascular involvement in IPF [19-22].

Statistical analysis

Statistical analyses were performed using Statistica version 6.0 (StatSoft France). Continuous variables were expressed as mean±SD or median [IQR], and categorical variables as number (%). Group comparisons used one-way ANOVA or the Kruskal–Wallis test for continuous variables and Pearson's χ^2 or Fisher's exact test for categorical variables, as appropriate. Intermediate/high echocardiographic PH probability was also compared with low probability in exploratory analyses. All tests were two-sided, with $p<0.05$ considered significant.

Results

Patient characteristics

The study included 27 patients with idiopathic pulmonary fibrosis. Baseline demographic and clinical characteristics are summarized in Table 1. DLCO measurements were unavailable in 10 patients and the six-minute walk test could not be completed in six patients because of advanced respiratory impairment.

PH-ILD Detection Tool risk categories

According to the PH-ILD Detection Tool, 14 patients (51.9%) were classified as low risk, five (18.5%) as intermediate risk and eight (29.6%) as high risk (Figure 1).

Echocardiographic PH probability and exploratory comparisons

Echocardiography classified 14 patients (51.9%) as having low PH probability, four (14.8%) as intermediate probability and nine (33.3%) as high probability (Table 2). The PH-ILD Detection Tool categories were subsequently compared with echocardiographic PH probability.

For exploratory analyses, patients were further categorised into intermediate/high echocardiographic PH probability (G1, n=13) and low echocardiographic PH probability (G2, n=14) (*Supplementary Tables 1-3, Supplementary Figure 1*, Table 3). Clinical, biomarker, imaging and functional variables were subsequently compared between the two echocardiographic PH probability groups (*Supplementary Table 2* and *Supplementary Figure 2*). Continuous comparisons across the three echocardiographic PH probability groups (Table 4) demonstrated significantly higher mean NT-proBNP concentrations ($p = 0.0467$), lower resting PaO_2 ($p = 0.0281$) and lower nadir SpO_2 ($p = 0.0071$) with increasing PH probability, whereas no significant differences were observed for the remaining variables. Thirteen of the 14 patients classified as low risk by the PH-ILD Detection Tool also had a low echocardiographic PH probability.

Discussion

In this prospective exploratory study, the PH-ILD Detection Tool identified 13 patients as having intermediate or high PH risk, while echocardiography classified 13 patients as having intermediate or high PH probability. Most patients classified as low risk also had a low echocardiographic PH probability. Higher PH probability was associated with greater

dyspnoea severity, elevated NT-proBNP concentrations, lower PaO_2 and greater exercise desaturation. These findings suggest that a multiparametric non-invasive approach may help prioritize patients for further cardiovascular evaluation in clinical practice. However, because right-heart catheterization was not performed, the present findings should be interpreted as exploratory rather than as diagnostic validation.

While the FORD index is the most validated PH detection tool in IPF, we opted to use the Parikh et al. PH-ILD detection tool, because it integrates routinely available clinical, imaging, physiological and biomarker variables into a composite score [17,18]. However, the present study did not directly compare the PH-ILD Detection Tool with the FORD model. Echocardiographic parameters, particularly the TAPSE/PASP ratio, have been reported as sensitive predictors of PH in ILD and correlate with pulmonary vascular resistance [23]**.** In our cohort, five patients with severe IPF (FVC ≤50%) had a TAPSE/PASP ratio ≤0.26. Because right-heart catheterization was not available, echocardiographic probability rather than haemodynamic confirmation was used for comparison.

Although dyspnoea is non-specific in IPF, worsening functional class has consistently been associated with pulmonary vascular involvement and poorer prognosis [24]. Dyspnoea severity was significantly associated with higher PH probability (p=0.005).

Regarding biomarkers, B-type natriuretic peptide (BNP) and N-terminal pro-BNP (NT-proBNP) are often elevated in ILD-associated PH. These biomarkers have proven useful for screening and prognostication. For instance, Sonti et al. reported significantly higher BNP levels in PH-ILD patients (738 pg/mL) versus non-PH-ILD patients (263 pg/mL). Similarly, in the Parikh et al. study (n=154), a NT-proBNP threshold of >300 pg/mL had 75.7% sensitivity and 61.3% specificity [15]. In our cohort, we observed a significant association between NT-proBNP >300 ng/L and intermediate/high PH probability (p=0.029). Similarly, mean NT-proBNP concentrations increased significantly across the three echocardiographic PH probability groups (Table 3; p = 0.0467).

Thoracic CT often reveals pulmonary artery (PA) enlargement in PH. The normal PA diameter is typically 27–29 mm [9], and the PA/Ao ratio has been proposed as an indicator of pulmonary vascular disease [1]. In contrast, neither pulmonary artery diameter nor the PA/Ao ratio was significantly associated with echocardiographic PH probability in our cohort, supporting the limited diagnostic value of isolated CT measurements in IPF [10]. However, our findings did not demonstrate a significant correlation between PA/Ao >0.9 and PH

probability, possibly due to aortic ectasia observed in two patients with intermediate PH probability.

Reduced diffusing capacity for carbon monoxide (DLCO) reflects the extent of alveolar-capillary membrane damage and perfusion heterogeneity in IPF-PH. Studies have suggested that PH should be suspected when DLCO is disproportionately reduced compared to radiologic or functional impairment [13]. A DLCO <45% has been associated with PH risk [25]. Additionally, a preserved FVC with a markedly reduced DLCO resulting in a FVC/DLCO ratio >1.6 can also suggest underlying vascular disease. In our cohort, however, no significant association was observed between these parameters and PH probability. This discrepancy may be due to the inability to perform DLCO testing in the most severe patients, which remains a challenge in real-world settings and highlights the need for alternative screening tools not dependent on patient cooperation. This absence of statistical significance should be interpreted cautiously because DLCO measurements were unavailable in several patients with advanced disease.

The coexistence of PH further impairs exercise capacity in ILD patients [14]. Lettieri et al. showed that reduced 6-minute walk test (6MWT) distance predicted PH in IPF. In another retrospective study involving IPF patients who underwent RHC and 6MWT, a higher mPAP was correlated with lower walking distance [26]. The FORD model by Nathan et al. confirmed a strong association between reduced 6MWT distance and PH in IPF but found no link with nadir SpO_2 [27]. Interestingly, our findings differed from those of Nathan et al.; whereas no significant association was observed with 6MWT distance, a significant association was found with nadir SpO_2.

Furukawa et al. included PaO_2 <80 mmHg as a screening criterion for PH in a study of 302 IPF patients, finding a strong correlation [28]. We also observed a significant association between PaO_2 ≤70 mmHg and increased PH probability ($p = 0.011$). This finding was supported by the continuous analysis, which demonstrated progressively lower mean resting PaO_2 across PH probability groups (Table 3; $p = 0.0281$). Likewise, mean nadir SpO_2 decreased significantly with increasing PH probability ($p = 0.0071$).

Strengths and limitations

This study has several strengths, including its prospective design, multidisciplinary diagnosis of IPF and systematic multiparametric assessment. However, several limitations should be acknowledged. First, the small single-centre sample limited statistical power. Second,

pulmonary hypertension was not confirmed by right-heart catheterization, and echocardiography provided only an estimate of PH probability. Third, DLCO and six-minute walk testing were incomplete in patients with advanced disease. Finally, the absence of an external validation cohort limits the generalizability of these findings. Therefore, the present results should be considered exploratory and hypothesis-generating.

Conclusions

The PH-ILD Detection Tool showed promising concordance with echocardiographic PH probability and may facilitate the identification of patients with IPF requiring further cardiovascular assessment. These exploratory findings require confirmation in larger multicentre studies using right-heart catheterization as the reference standard.

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Online supplementary material
Supplementary Table 1. Clinical and anamnestic variables by pulmonary hypertension probability.
Supplementary Table 2. Computed tomography parameters by pulmonary hypertension probability.
Supplementary Table 3. Pulmonary function parameters by pulmonary hypertension probability.
Supplementary Figure 1. Computed tomography parameters by echocardiographic pulmonary hypertension probability.
Supplementary Figure 2. Heatmap of correlation p-values for pulmonary hypertension screening variables.

Table 1. Baseline demographic and clinical characteristics of the study population (n=27).

Characteristic	Value
Age (mean ± SD)	67.77 ± 9.25 years
Sex (M/F)	22 M / 5 F
Smoking history (current/former)	16 patients (59.25%)
Syncope / Pre-syncope	11 patients (40.74%)
Hyperinflation	3 patients (11.11%)
Excessive fatigue	18 patients (66.67%)
Dyspnea (NYHA class, mean ± SD)	2.66 ± 1.07
Data are presented as mean ± standard deviation (SD) or n (%), as appropriate. Abbreviations: M, male; F, female; NYHA, New York Heart Association functional class.	

Table 2. Echocardiographic parameters by Parikh Score Group.

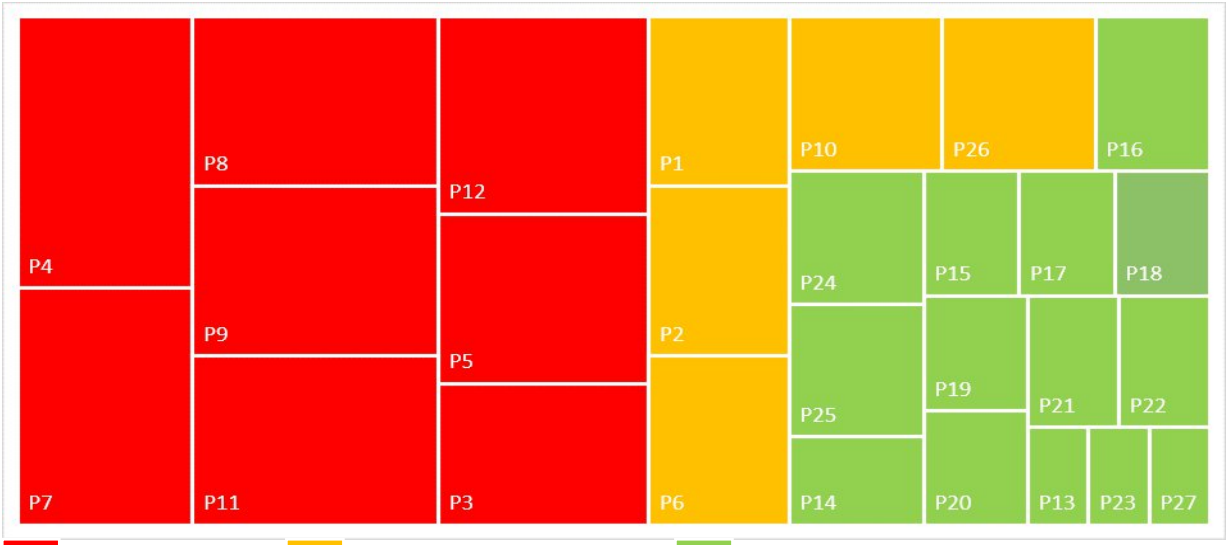
Parameter	Low Score (n=14)	Intermediate Score (n=5)	High Score (n=8)
sPAP (mmHg)	31.42	48.4	61.62
TAPSE (mm)	22.5	15.5	18.78
TAPSE/sPAP	0.79	0.38	0.33
TR Vmax (m/s)	2.52	3.11	3.55
sPAP: systolic pulmonary artery pressure; TAPSE: tricuspid annular plane systolic excursion; TR Vmax: peak tricuspid regurgitation velocity.			

Table 3. Mean values of surveillance parameters by PH probability.

Variable	High PH Probability	Intermediate PH Probability	Low PH Probability	TEST	p
BNP (NG/L)	1239.22±2211.74 (n=9)	716.50±702.18 (n=4)	140.00±112.20 (n=14)	Kruskal-Wallis	**0,0467**
AP (MM)	31.30±3.98 (n=9)	29.25±3.30 (n=4)	28.47±4.36 (n=14)	ANOVA	0,2896
AO (MM)	31.94±3.07 (n=9)	35.75±3.30 (n=4)	32.74±4.88 (n=14)	ANOVA	0,3246
AP/A	0.99±0.15 (n=9)	0.82±0.10 (n=4)	0.88±0.11 (n=14)	ANOVA	0,0612
CVF (%)	54.67±25.80 (n=9)	52.50±12.07 (n=4)	70.57±21.62 (n=14)	ANOVA	0,173
DLCO (%)	59.00±11.31 (n=2)	32.50±0.71 (n=2)	60.27±16.97 (n=11)	Kruskal-Wallis	0,1718
CVF/DLCO	1.40±0.45 (n=2)	1.52±0.69 (n=2)	1.19±0.28 (n=11)	Kruskal-Wallis	0,4595
DISTANCE (METRE)	260.00±157.00 (n=5)	246.67±133.17 (n=3)	330.42±91.32 (n=12)	ANOVA	0,3748
NADIR SPO2 (%)	78.20±7.73 (n=5)	74.33±5.86 (n=3)	89.92±5.28 (n=12)	Kruskal-Wallis	**0,0071**
PAO2 (MMHG)	59.22±17.37 (n=9)	60.25±8.22 (n=4)	79.08±18.09 (n=12)	ANOVA	**0,0281**
Data are presented as mean ± standard deviation (SD). Continuous variables were compared using one-way ANOVA when normality was confirmed in all three groups (Shapiro–Wilk test, n ≥ 3 per group); otherwise, the Kruskal–Wallis test was used. Statistically significant p values (<0.05) are shown in bold. DLCO and FVC/DLCO results should be interpreted with caution because of the very small sample size (n = 2) in the intermediate- and high-PH probability groups. Abbreviations: FVC, forced vital capacity; DLCO, diffusing capacity of the lung for carbon monoxide; PaO_2, arterial partial pressure of oxygen; 6MWT, six-minute walk test; SpO_2, peripheral oxygen saturation.					

Table 4. Association of screening variables with intermediate/high echocardiographic PH probability.

Variable	G1	G2	p-value
NYHA	III±1	II±1	0.005*
Syncope	61.5%	21.4%	0.034*
Hyperinflation	15.4%	71.4%	0.514
Fatigue	84.6%	50%	0.050*
NT-proBNP ≥ 300ng/L	53.8%	14.3%	0.029*
PA ≥30 mm	69.2%	42.9%	0.181
PA/Ao ≥ 0.9	61.5%	50%	0.564
FVC ≤ 50%	46.2%	14.3%	0.074
DLCO ≤ 40%	50%	9%	0.090
FVC/DLCO ≥ 1.6	50%	9%	0.090
6MWT ≤ 350m	62.5%	53.8%	0.714
Nadir SpO_2 ≤ 82%	75%	7.7%	<0.001*
PaO_2 ≤70 mmHg	69.2%	21.4%	0.011*
PASP ≥45 mmHg	69%	0%	<0.001*
TAPSE ≤ 18 mm	60%	0%	0.001*
TR Vmax ≥ 2.8 m/s	88.9%	0%	<0.001*
TAPSE/PASP ≤ 0.26	50%	0%	0.007*
G1: intermediate/high echocardiographic PH probability, n=13; G2: low echocardiographic PH probability, n=14.			



High risk (n=8). intermediate risk (n=5). Low risk (n=14).

Figure 1. Distribution of patients according to PH-ILD Detection Tool risk category.