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Epidemiology and Clinical Features of Pulmonary Fungal Infections in Patients with Pneumonia: A Single-Center Study from Southwestern Iran

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Abstract

Background: Pulmonary fungal infections (PFIs) are opportunistic infections that pose a serious threat to immunocompromised patients. Early diagnosis is challenging, and region-specific epidemiological data from southwestern Iran remain limited**.**

Methods: In this cross-sectional study (June 2022–June 2023), 139 hospitalized patients with suspected fungal pneumonia at Imam Khomeini Hospital, Ahvaz, were evaluated according to EORTC/MSG 2020 criteria. Clinical samples underwent direct microscopy, culture, serological testing (galactomannan, 1,3-β-D-glucan), and calmodulin gene sequencing for *Aspergillus*isolates. Demographics, comorbidities, clinical signs, and chest CT findings were recorded.

Results: PFIs were diagnosed in 58 patients (41.7%). Among them, 7 were proven (5%) and 51 probable (36.6%). *Aspergillus* species predominated (72.4% of PFIs), mainly sections *Flavi* and *Nigri*, followed by *Pneumocystis jirovecii* (19.0%) and *Mucorales* (8.6%). Common comorbidities included diabetes (29.3%) and prior COVID-19 infection (24.1%). Fever (58.6%) and cough (53.4%) were the most frequent symptoms. Cavitation (39.6%) and consolidation (37.9%) were the leading CT findings. Mortality in the PFI group was 25.8%, higher than in the overall cohort (20.9%). Male sex and prior COVID-19 infection were significantly associated with PFIs.

Conclusions: PFIs, predominantly aspergillosis, are highly prevalent among pneumonia patients in southwestern Iran. Early recognition through combined radiological, mycological, and serological evaluation, along with attention to predisposing factors such as COVID-19 and male sex, is essential. These findings provide critical region-specific epidemiological insights to guide targeted diagnostic and therapeutic strategies and improve patient outcomes.

1. Introduction

Pulmonary fungal infections (PFIs), caused by a diverse spectrum of yeasts and molds with distinct antifungal susceptibility profiles, represent a significant and growing clinical concern, particularly among immunocompromised hosts (1). The early and accurate diagnosis of PFIs is crucial for improving therapeutic outcomes and reducing associated morbidity and mortality in this vulnerable population. Over the past two decades, significant research efforts have focused on enhancing diagnostic approaches for PFIs. Among these, serological assays such as galactomannan (GM) and 1,3-β-D-glucan (BG) have emerged as valuable non-invasive tools for early detection, with reported sensitivities and specificities exceeding 60% in prior studies(2, 3). Despite these advances, the timely and accurate diagnosis of PFIs remains a clinical challenge, yet it is essential for guiding targeted therapy. Current diagnostic criteria, as outlined in the EORTC/MSG 2020 guidelines, integrate host factors, clinical manifestations, and mycological evidence. While the lungs are the primary site of infection, clinical presentation can be variable; common symptoms include cough, fever, hemoptysis, and chest pain, though they may not be universally present (4, 5). Imaging findings on chest computed tomography (CT), while often abnormal (e.g., nodules, cavitation’s), are notoriously nonspecific for PFIs (6). Consequently,

the current understanding of PFI epidemiology in Khuzestan province, especially in Ahvaz, remains fragmentary and insufficient. This critical knowledge deficit not only obscures the true disease burden but also impedes the optimization of local diagnostic pathways and treatment frameworks. Therefore, generating robust, evidence-based insights into the endemicity, emerging trends, and diagnostic hurdles of fungal pneumonias in this region is an indispensable step toward improving clinical outcomes and shaping effective health policy.

2. Objectives

Given the nonspecific clinical presentation and the limitations of conventional diagnostic methods for pulmonary fungal infections (PFIs), this study aimed to comprehensively evaluate PFIs among patients with pneumonia at Imam Khomeini Hospital in Ahvaz, southwestern Iran. The specific objectives were to:

1. Determine the prevalence and distribution of PFI-causative agents in the study population.
2. Characterize the clinical features, risk factors, and chest computed tomography (CT) findings associated with confirmed PFI cases.
3. Assess the diagnostic utility of mycological (culture and microscopy) and serological (galactomannan and 1,3-β-D-glucan) methods in our setting.
4. Propose an optimized diagnostic algorithm to facilitate earlier and more accurate identification of PFIs, thereby improving clinical management and patient outcomes.

To our knowledge, this represents the first investigation to systematically delineate the epidemiological, clinical, and diagnostic profile of PFIs complicating pneumonia in southwestern Iran.

3. Methods

3.1. Study Design and Participants

This study is cross-sectional research performed in Imam Khomeini Hospital in Ahvaz from June 2022 to June 2023 (a period of 12 months). Eventually, 139 patients with suspected fungal pneumonia and admitted to hospital entered this work. This study used the classification of pulmonary fungal diseases according to the recent EORTC/MSGERC (European Organization for Research and Treatment of Cancer and the Mycoses Study Group Education and Research Consortium) 2020 criteria (7).

Inclusion criteria were: (1) presence of at least one host factor (e.g., prolonged corticosteroid use, hematological malignancy, solid organ transplant, diabetes mellitus, active tuberculosis, or post-COVID-19 pulmonary sequelae); and (2) clinical evidence of lower respiratory tract infection, manifested as new or worsening respiratory symptoms (e.g., productive cough, dyspnea, hemoptysis, or pleuritic chest pain).

Exclusion criteria included: (1) receipt of systemic antifungal therapy for > 72 hours within the 3 days preceding sample collection; and (2) unwillingness to participate in the study.

3.2. Clinical Data and Sample Collection

For each participant, a standardized case report form was used to collect demographic characteristics, underlying comorbidities, clinical symptoms, laboratory parameters, chest computed tomography (CT) findings, treatment details, and clinical outcomes.

Clinical specimens were obtained based on the patient's condition and clinical indication as follows:

1. Sputum: Early-morning, deep-cough sputum samples (5–10 mL) were collected from 44 patients into sterile containers.
2. Bronchoalveolar Lavage (BAL): BAL fluid was obtained from 63 mechanically ventilated patients using a sterile, white-light flexible bronchoscope under standard protocol.
3. Tracheal Aspirate: Transtracheal aspiration was performed on 24 non-ventilated patients using a percutaneous catheter technique via the cricothyroid membrane.
4. Tissue Biopsy: Lung tissue specimens were acquired from 4 patients via CT-guided fine-needle aspiration or surgical biopsy for histopathological correlation.
5. Blood: Two milliliters of venous blood were collected from all participants (n = 139) in sterile tubes for serological testing.

All samples were transported to the mycology laboratory within 2 hours of collection for immediate processing.

3.3. Microbiological and Mycological Analyses

3.3.1. Direct Microscopy

Direct smears from respiratory samples and tissue biopsies were prepared and examined using potassium hydroxide (KOH; 10%), aniline blue stain, and Giemsa stain. Slides were screened under a light microscope (×400 and ×1000 magnification) for the presence of fungal elements such as hyphae, yeast cells, or sporangia.

3.3.2. Fungal Culture

All clinical specimens were inoculated onto Sabouraud Dextrose Agar (SDA) supplemented with chloramphenicol (Condalab, Spain) and incubated in duplicate at 25°C and 35°C for up to 4 weeks. Cultures were examined three times per week during the first two weeks and weekly thereafter. Fungal isolates were identified based on macroscopic colony morphology and microscopic characteristics using lactophenol cotton blue mounts, with reference to standard mycological texts(8).

3.4. Serological Assays

Serum samples were tested for:

1. Galactomannan (GM): Using a commercial enzyme immunoassay kit (Bioactiva Diagnostica, Germany) according to the manufacturer's instructions. An optical density index (ODI) of ≥ 0.5 was considered positive.
2. 1,3-β-D-Glucan (BDG): Detection was performed using the Dynamiker Fungus (1–3)-β-D-Glucan assay (Dynamiker Biotechnology, China). Results were interpreted as follows: <70 pg/mL (negative), 70–94 pg/mL (indeterminate), and ≥ 95 pg/mL (positive), per the kit's guidelines.

3.5. Molecular Identification

Species-level identification of the *Aspergillus* isolates was confirmed by sequencing a fragment of the calmodulin (*CaM*) gene. Genomic DNA was amplified using primers cmd5 and cmd6. The PCR protocol included an initial denaturation (95°C, 5 min), 35 cycles (94°C, 45 s; 45°C, 60 s; 60°C, 72 s), and a final extension (72°C, 5 min). Due to budgetary constraints, sequencing was performed only for two isolates from each section. Amplicons were purified, sequenced and edited. Species were assigned based on ≥ 99% similarity to validated reference sequences in the GenBank database using BLAST analysis.

3.6. Statistical Analysis

The collected data were tabulated and statistically analyzed using the following methods: (1) descriptive statistics: the continuous data were represented as mean and SD, while the non-numerical data were represented as number and percentage; (2) Analytic statistics: (a) one-way analysis of variance test for rank (Kruskal–Wallis). This test was used to compare more than two groups of numerical origin; (b) Pearson's $\chi 2$ test: the test was used to test the association between the categorical variables. All statistical tests were two-sided and the p-value was considered significant if it was less than 0.05.

4. Results

4.1. Patient Characteristics and Study Flow

Initially, 165 patients with suspected fungal pneumonia were screened. Twenty-six patients were excluded due to either lack of consent (n = 14) or inadequate sample quality (n = 12), leaving 139 patients for final analysis. The cohort comprised 91 (65.5%) males and 48 (34.5%) females, with a mean age of 49 years. Based on clinical, radiological, and mycological criteria, patients were categorized into three groups: confirmed/probable pulmonary fungal infection (PFI) (n = 58, 41.7%), colonization (n = 5, 3.6%), and no evidence of fungal infection (n = 76, 54.7%). The overall mortality rate was 20.9% (29/139), which was higher among patients in the PFI group (25.8%, 15/58). Demographic and baseline clinical characteristics are detailed in Table 1.

Table 1
The demographic and clinical characteristics of all the patients who entered our study

Attributes	Patients with infections (n = 58)	Patients without infections (n = 76)	Colonization (n = 5)	P-value
Age	52.45 ± 16.302	45.91 ± 9.74	49.60 ± 24.906	0.391
Sex				0.049*
Male	42	44	5	
Female	16	32	0	
Duration of hospitalization				0.978
Less than 14 days	48	62	4	
More than 14 days	10	14	1	
Underlying disease				
Cancer	5	5	1	0.54
Organ transplant	3	0	0	0.118
Tuberculosis	7	7	0	0.645
Blood pressure	11	13	1	0.955
Diabetes	17	12	1	0.169
COVID-19	14	7	0	0.036*
ARDS	3	1	0	0.386
HIV	2	1	0	0.663
Disease				
Bronchiectasis	6	6	1	0.629
Asthma	2	6	0	0.469
Cartagena syndrome	0	3	1	0.026*
COPD	5	4	1	0.401
Treatment history				
Hospitalization in ICU	24	26	0	0.161

* P ≤ 0.05 is statistically significant.

Attributes	Patients with infections (n = 58)	Patients without infections (n = 76)	Colonization (n = 5)	P-value
Corticosteroid	23	16	1	0.056
Clinical symptoms				
Fever	34	32	1	0.470
Cough	31	34	2	0.566
Hemoptysis	14	11	1	0.363
Chest pain	2	7	0	0.339
* P ≤ 0.05 is statistically significant.				

4.2. Clinical Presentations and Underlying Conditions

The most common comorbidities among PFI patients were diabetes mellitus (29.3%, 17/58) and a history of COVID-19 (24.1%, 14/58). The predominant clinical manifestations included fever (58.6%), cough (53.4%), and hemoptysis (24.1%). Corticosteroid use prior to diagnosis was recorded in 39.6% (23/58) of PFI patients, while 75.1% (43/58) presented with varying grades of neutropenia (Fig. 1).

4.3. Mycological and Diagnostic Profile

Among the 58 patients classified with PFI, 7 (12%) met the criteria for proven infection and 51 (88%) for probable infection according to the EORTC/MSG 2020 criteria. Mycological identification from clinical specimens revealed Aspergillus species as the predominant agents (n = 42, 72.4% of PFIs), followed by *Pneumocystis jirovecii* (n = 11, 19.0%) and *Mucorales* (*Rhizopus* species) (n = 5, 8.6%). Among the Aspergillus isolates, identification by section was as follows: section Flavi (n = 16), section *Nigri* (n = 14), section *Fumigati* (n = 8), and section *Terrei* (n = 4). The five colonization cases grew *Aspergillus* species from sections *Flavi* (n = 3) and *Nigri* (n = 1), along with one *Paecilomyces* species, but lacked corresponding clinical or serological evidence of invasive disease. The spectrum of mycological and serological results, categorized by sample type, is summarized in Fig. 2 for all patients included in the analysis (n = 139). The etiological distribution of fungal pathogens identified in patients with proven and probable PFIs is presented in Fig. 3

4.4. Radiological Findings

Chest CT imaging in PFI patients most frequently revealed cavitary lesions (39.6%) and consolidation (37.9%). Statistical analysis demonstrated a significant association between the presence of PFI and specific CT patterns: consolidation (p = 0.011) and ground-glass opacities (GGO) (p = 0.001). Radiological findings are comprehensively presented in Table 2.

Table 2
CT chest findings of patients with pulmonary fungal infections

CT imaging features	PJP Pneumonia (N = 11)	Aspergillosis (N = 42)	Mucormycosis (N = 5)	P-value
CT scan results				
Nodule	0	4	1	0.386
Consolidation	3	14	5	0.011*
Atelectasis	0	1	0	0.824
GGO	7	5	1	0.001*
Tree-in-bud	0	1	0	0.824
Cavitation	2	18	3	0.206
Lung emphysema	2	2	0	0.240
Pleural effusion	2	3	0	0.394
Mass	1	2	0	0.729
Wing fungus	0	3	0	0.547
Halo sign	0	2	0	0.674
Necrosis	0	1	0	0.824
Outcome				0.511
Recovery	2	7	2	
Death	4	11	0	
Discharge	3	24	5	
* P ≤ 0.05 is statistically significant.				

4.5. Laboratory Parameters and Statistical Associations

Comparative analysis of laboratory parameters across the three patient groups (PFI, colonization, no infection) revealed several significant associations (Table 3). Erythrocyte sedimentation rate (ESR) was significantly higher in the PFI group compared to the no-infection group ($p = 0.026$). Alanine aminotransferase (ALT) levels differed significantly between the PFI and no-infection groups ($p < 0.001$) and between the PFI and colonization groups ($p = 0.007$). Similarly, serum creatinine (Cr) levels were significantly elevated in PFI patients compared to those without infection ($p < 0.001$).

Table 3
The laboratory results of the patients with pulmonary fungal infection

Name of laboratory tests	Patients with infections (n = 58)	Patients without infections (n = 76)	Colonization (n = 5)	P-value
ESR (mm/hr)	60.98 ± 33.699	46.97 ± 35.989	34.00 ± 34.850	0.014*
LDH (U/L)	574.74 ± 382.88	483.04 ± 503.062	359.00 ± 21.953	0.055
ALT (U/L)	58.87 ± 34.172	35.11 ± 53.903	20.20 ± 5.263	0.00*
WBC ($\times 10^9$/L)	16.1924 ± 12.99352	13.6334 ± 10.49615	11.8000 ± 2.93172	0.219
Neut %	79.9241 ± 15.83154	75.7105 ± 15.26436	68.7000 ± 22.20822	0.063
Cr (μmol/L)	1.359 ± 0.8450	0.972 ± 0.4974	0.980 ± 0.5975	0.00*
CRP (μg/mL)				0.006*
+	46	40	3	
	12	36	2	

* P ≤ 0.05 is statistically significant.

4.6. Molecular Confirmation of Aspergillus Isolates

Two morphologically identified isolates from each target section (*Flavi*, *Terrei*, *Fumigati*, *Nigri*) were subjected to calmodulin gene sequencing. BLAST analysis confirmed their identity as *Aspergillus flavus* (PQ582289, PQ582286), *A. terreus* (PQ582326, PQ582324), *A. fumigatus* (PQ582331, PQ582338), and *A. niger* (PQ582320, PQ582308), validating the phenotypic identification.

5. Discussion

Globally, pulmonary fungal infections (PFIs) represent a major cause of morbidity among immunocompromised patients, particularly those receiving immunosuppressive therapies or admitted to intensive care units (ICUs). Empirical antifungal therapy in high-risk populations is often associated with significant limitations, including drug-related toxicity and increased healthcare costs resulting from inappropriate or ineffective treatment. Therefore, early identification of patients at risk and the use of sensitive, yet practical, diagnostic approaches are essential to enable targeted antifungal therapy.

Although Candida species are frequently isolated from respiratory tract specimens, their presence generally reflects colonization rather than true infection, and antifungal therapy is rarely indicated in non-neutropenic patients. Accordingly, the current study focused on fungal pathogens other than Candida species. Aspergillus species were identified as the predominant causative agents, accounting for 30% of

cases, followed by *Pneumocystis jirovecii* (7.9%) and Mucor species (3.6%). These findings are consistent with the recognized role of filamentous fungi and opportunistic pathogens as leading causes of invasive pulmonary fungal infections in immunocompromised hosts.

In recent years, only a limited number of studies, both in Iran and internationally, have comprehensively evaluated fungal pneumonia using standardized diagnostic criteria. Moreover, many earlier reports did not apply the EORTC/MSG criteria and often considered the isolation of Candida species from respiratory secretions as evidence of fungal pneumonia, potentially leading to an overestimation of disease prevalence (9, 10). When Candida species are included, the reported incidence of fungal pneumonia has ranged widely from 12% to 67% (11-13), underscoring the heterogeneity of diagnostic approaches across studies.

Invasive Pulmonary Aspergillosis

Previous studies have reported a wide range in the prevalence of invasive pulmonary aspergillosis (IPA) caused by *Aspergillus* species, varying from 9.9% to 57% (9–12, 14, 15). According to the EORTC/MSG criteria, all IPA cases identified in the present study were classified as probable, accounting for 30% of the study population. Notably, a recent study conducted in 2023 by Song et al. in Shandong, China, reported an IPA prevalence of 32.8% among patients with severe fever with thrombocytopenia syndrome, a finding comparable to that observed in our study (16). Variations in reported prevalence rates may be attributed to diagnostic challenges, differences in sample quality, heterogeneity of study populations, geographic factors, and the use of diagnostic methods or definitions not fully aligned with EORTC/MSG criteria.

In the current study, *Aspergillus flavus* was the most frequently isolated species (23.52%), followed by *A. terreus* and *A. fumigatus* (each 13.72%). While most studies conducted outside Iran identify *A. fumigatus* as the predominant cause of IPA, domestic studies consistently report *A. flavus* as the leading etiologic agent (**10, 17, 18, 20, 21**). This discrepancy strongly suggests a geographic influence on species distribution, possibly related to environmental and climatic factors, highlighting the importance of regional surveillance to guide empiric therapy.

Pneumocystis jirovecii Pneumonia

Regarding *Pneumocystis jirovecii* pneumonia (PJP), reported prevalence rates vary considerably across different populations. Studies from Iran and other countries have documented PJP prevalence ranging from 9% in lung cancer patients (22) to 33% in patients with interstitial lung disease (23, 24). Similarly, Babic-Erceg et al. reported a prevalence range of 1.5% to 56.6% across diverse populations in Croatia (25). In the present study, PJP was identified in 7.9% of patients. Importantly, all patients with pulmonary symptoms suspected of PJP were included regardless of underlying conditions, which may partly explain the lower prevalence observed. Differences in diagnostic techniques, laboratory expertise, and population characteristics likely contribute to the variability in reported rates.

Consistent with previous reports, ground-glass opacity (GGO) was the most common CT scan finding among patients with PJP, observed in 63% of cases. This finding aligns closely with earlier studies reporting GGO in approximately 66% of PJP patients, further supporting the diagnostic relevance of radiological features in this infection (26).

Taken together, these findings underscore the importance of region-specific epidemiological data for both IPA and PJP**.** Our study not only confirms the predominance of *A. flavus* in Iran but also provides updated prevalence estimates of PJP in a heterogeneous pulmonary patient population, filling a critical knowledge gap and informing targeted diagnostic and therapeutic strategies.

Pulmonary Mucormycosis

Pulmonary mucormycosis is a rare but severe fungal infection, predominantly affecting immunocompromised patients. Most published data on pulmonary mucormycosis are limited to isolated case reports (27). In the present study, five cases (3.59%) were identified, including three confirmed and two probable cases based on EORTC/MSG criteria. The predominant CT scan finding in all affected patients was consolidation, which is consistent with previous studies identifying this pattern as a characteristic radiological feature of advanced pulmonary mucormycosis (28)

Demographic Factors: Age and Sex

Contrary to initial expectations, no statistically significant difference in age was observed between patients with and without PFIs ($p = 0.29$). This finding may be attributable to the relatively homogeneous age distribution of the study population. Nevertheless, patients with fungal infections had a higher mean age (52.45 ± 16.30 years) compared with non-infected individuals (45.91 ± 9.74 years), indicating a clinically relevant age trend. In line with this observation, a meta-analysis demonstrated that patients with aspergillosis pneumonia were, on average, approximately 2.5 years older than those without infection ($p < 0.0001$), supporting the association between increasing age and susceptibility to invasive fungal diseases (29).

In addition, male patients were 2.5 times more likely to develop fungal pneumonia than female patients (72% vs. 28%; $p = 0.049$). This sex disparity is consistent with findings reported by Li et al., who also observed a significantly higher prevalence of fungal pneumonia among men (15). Biological sex differences, including variations in sex hormone regulation and innate and adaptive immune responses, are increasingly recognized as important determinants in the epidemiology of infectious diseases. A comprehensive systematic review and meta-analysis of invasive fungal infections further demonstrated a clear male predominance across most IFDs, including invasive aspergillosis (51%), mucormycosis (60%), cryptococcosis (74%), coccidioidomycosis (70%), histoplasmosis (61%), and blastomycosis (66%), with candidiasis being the primary exception (30, 31).

Collectively, these findings highlight the importance of incorporating demographic factors such as age and biological sex into risk assessment models for pulmonary fungal infections. Such an approach may

improve early recognition, optimize diagnostic strategies, and support more targeted therapeutic decision-making, particularly in immunocompromised and high-risk patient populations.

Clinical Implications

Taken together, these results highlight the heterogeneity of pulmonary fungal infections in terms of etiology, radiological presentation, and demographic risk factors. Importantly, this study provides updated, region-specific epidemiological data using standardized diagnostic criteria, addressing a critical gap in the existing literature. Such data are essential for improving risk stratification, optimizing diagnostic algorithms, and guiding targeted antifungal therapy in immunocompromised and critically ill patients.

In the present study, corticosteroid use was associated with an approximately 1.5-fold increased risk of fungal pneumonia. Corticosteroids are known to impair both local and systemic immune responses, thereby facilitating pathogen colonization and increasing susceptibility to invasive fungal infections (32).

Our analysis further demonstrated that several laboratory parameters, including ESR, alanine aminotransferase (ALT), creatinine (Cr), and high-sensitivity C-reactive protein (hs-CRP), differed significantly between patients with and without fungal pneumonia ($p < 0.05$). Although these markers lack specificity, their elevated sensitivity suggests that—when interpreted in conjunction with clinical and radiological findings—they may serve as useful adjuncts in the diagnostic evaluation of pulmonary fungal infections. Previous studies have reported increased creatinine levels in patients with fungal infections (33), as well as hepatic involvement associated with non-*Candida* yeasts, filamentous fungi, and dimorphic fungi (34,35). Nevertheless, further studies are warranted to clarify the relationship between these laboratory indicators—particularly creatinine and ALT—and PFIs, despite reports indicating elevated ALT levels in patients with *Pneumocystis jirovecii* pneumonia (36).

Additionally, our findings indicate that patients with COVID-19 had a twofold higher risk of developing fungal pneumonia, with a statistically significant association observed between COVID-19 infection and fungal pneumonia status ($p = 0.036$). These results support the consideration of COVID-19 as an important predisposing factor for pulmonary fungal infections. Careful clinical monitoring and individualized risk assessment may therefore be warranted in this patient population, while decisions regarding antifungal prophylaxis should be made cautiously and, on a case,-by-case basi.

6. Conclusions

Pulmonary fungal infections (PFIs) are significant opportunistic infections with high prevalence among both neutropenic and non-neutropenic patients, predominantly influenced by host-related factors. In Iran, *Aspergillus flavus* was identified as the most common pathogenic species, underscoring the importance of region-specific epidemiological data. Accurate diagnosis remains challenging due to the overlap of clinical manifestations with other types of pneumonia, necessitating a combined approach integrating

radiological evaluation, underlying comorbidities, and comprehensive mycological and serological testing.

This study further highlights COVID-19 as a notable predisposing factor for PFIs, with increased susceptibility observed among male patients. Serological assays emerged as valuable adjuncts, and in selected clinical scenarios, potential alternatives to invasive diagnostic procedures. Laboratory parameters such as ALT, creatinine, ESR, and hs-CRP may provide supportive information for early detection, although their specificity is limited.

Overall, these findings provide updated, region-specific epidemiological and clinical insights into PFIs, emphasizing the need for refined diagnostic criteria, vigilant risk stratification, and timely prophylactic or therapeutic interventions. Continued research is essential to improve early detection, optimize targeted antifungal therapy, and ultimately enhance outcomes in vulnerable patient populations.

Declarations

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Consent for publication: Not applicable.

Availability of data and materials: The datasets generated and/or analyzed during the current study are not publicly available due to ethical and privacy considerations but are available from the corresponding author, Dr. Neda Kiasat (email: nedakiasat1402@gmail.com), upon reasonable request and with appropriate ethical approval.

Competing interests: The authors declare that they have no competing interests.

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Figures

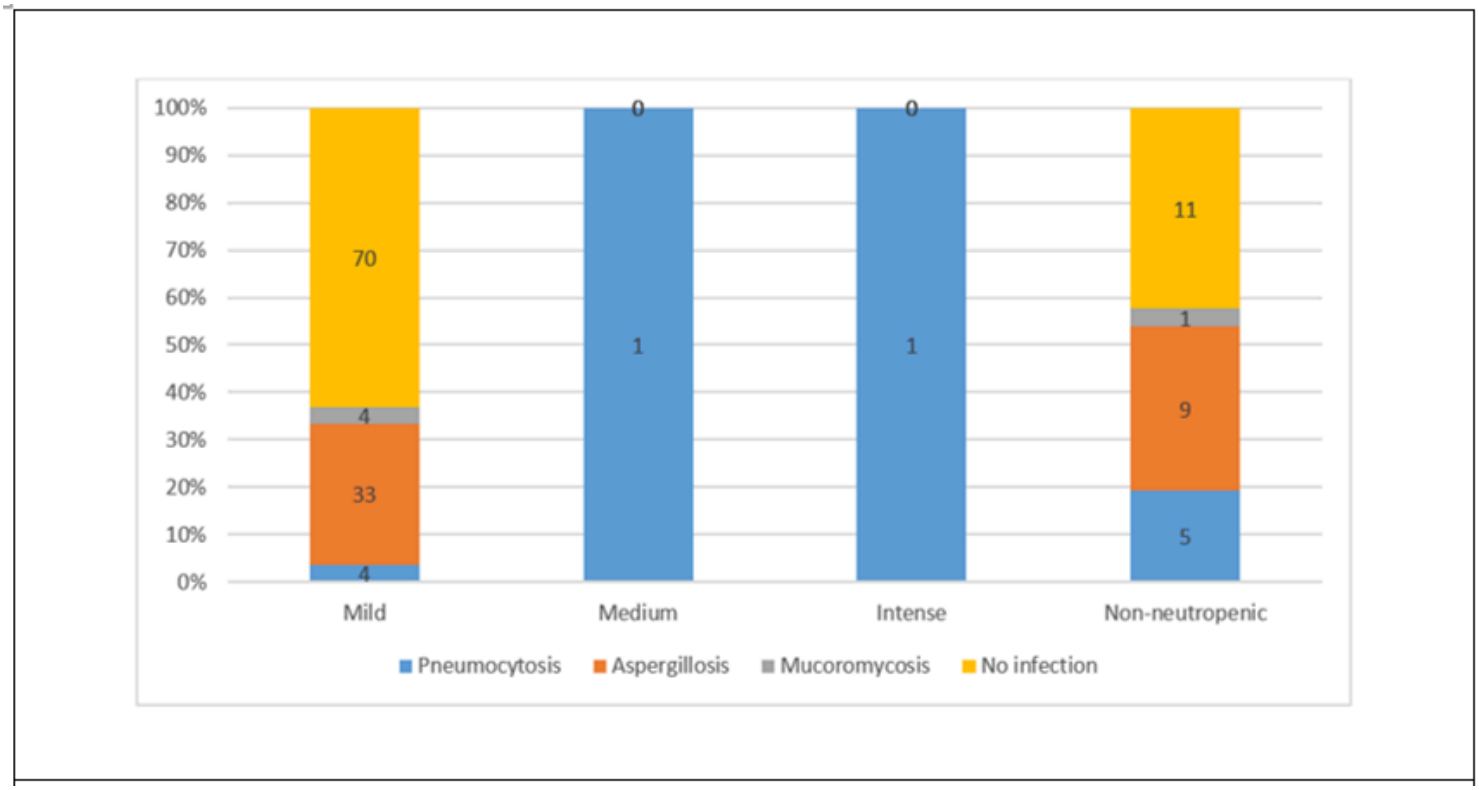


Figure 1

The distribution of neutropenia and non-neutropenia in patients with and without pulmonary fungal infections (n=139). The numbers on the column represent the numbers of patients. Each color on the columns represents one type of pulmonary fungal infection.

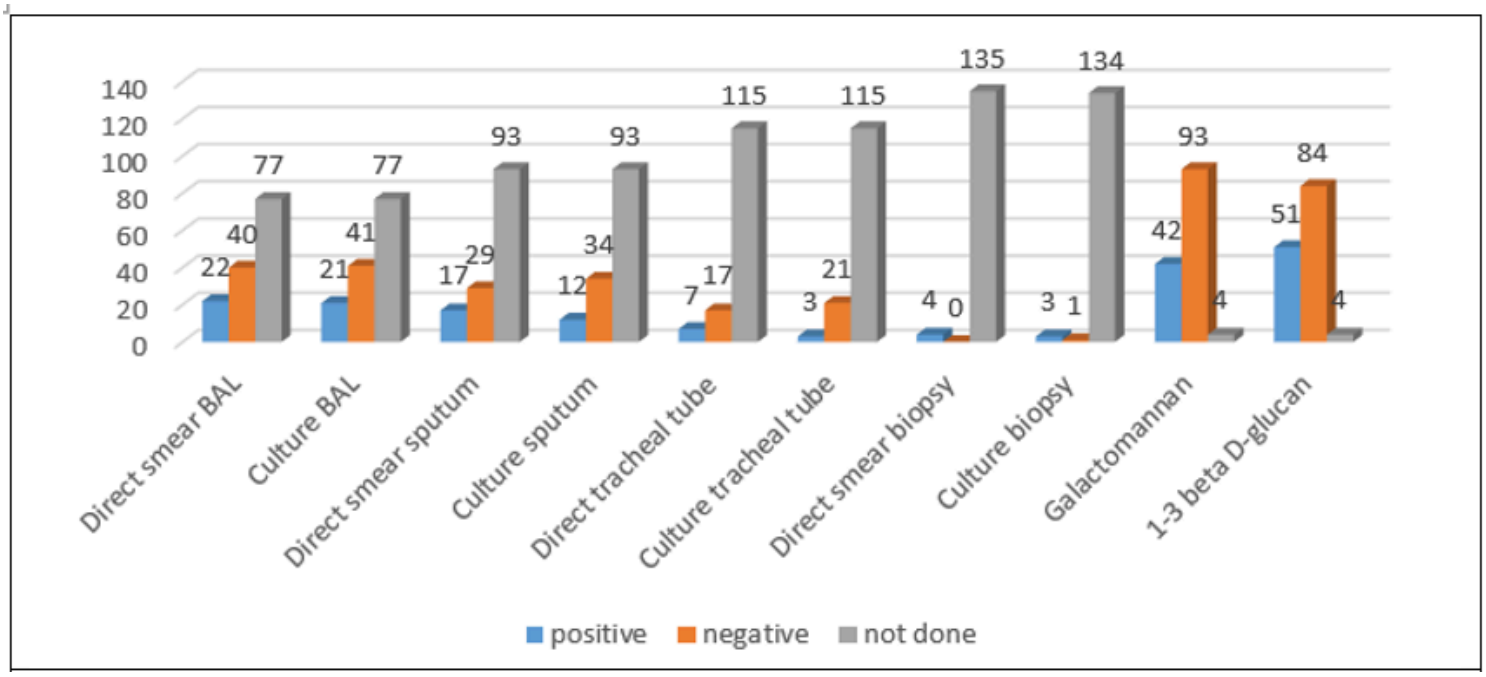


Figure 2

The mycological and serological results of patients with pulmonary pneumonia (n=139) in different samples sent to the laboratory. The numbers on the columns represent the number of patients.

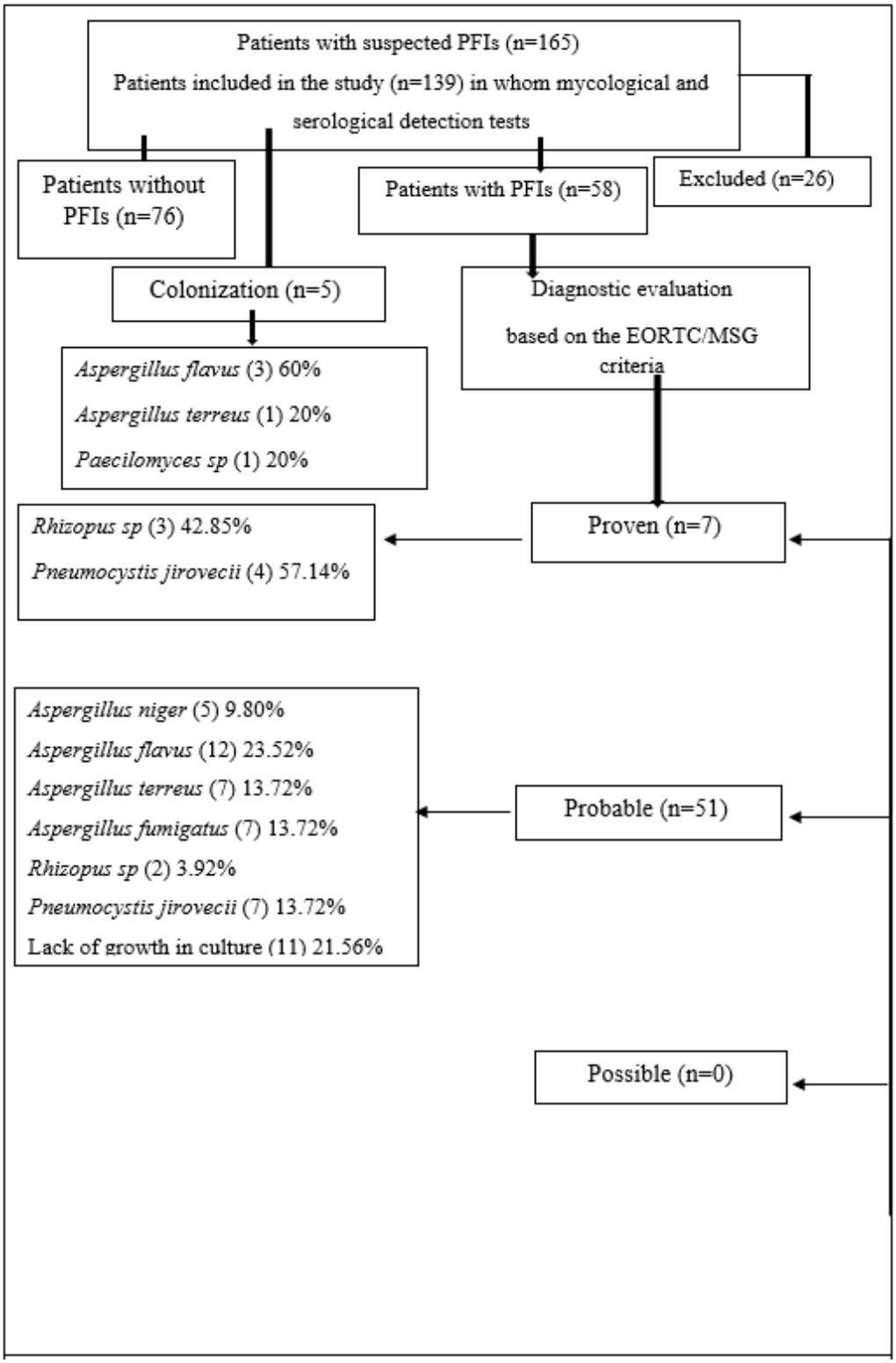


Figure 3

The outline and summary of the results of this study.