Respiratory Fungal Diseases in Adult Patients With Cystic Fibrosis

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ABSTRACT: Clinical manifestations of respiratory fungal diseases in adult cystic fibrosis (CF) patients are very heterogeneous, ranging from asymptomatic colonization to chronic infections, allergic disorders, or invasive diseases in immunosuppressed CF patients after lung transplantation. In this narrative review, mainly addressed to clinicians without expertise in CF who may nonetheless encounter adult CF patients presenting with acute and chronic respiratory syndromes, we briefly summarize the most representative clinical aspects of respiratory fungal diseases in adult CF patients.

KEYWORDS: Cystic fibrosis, ABPA, *Aspergillus*, *Candida*, *Scedosporium*, *Exophiala*, *Lomentospora*, CFTR, bronchitis, sensitization

Introduction

Cystic fibrosis (CF) is an autosomal recessive disease, characterized by multiorgan involvement and usually clinically dominated by chronic bacterial respiratory infection and bronchiectasis, with alternation of acute pulmonary exacerbations and interexacerbation periods, and progressive loss of lung function.[1] The estimated prevalence of CF in Europe and the United States is of 20 and 50 cases per 100 000 inhabitants, respectively.[2]

In the last decades, a notable increase in the average life expectancy of CF patients has been registered, reaching 42 to 51 years for those born between 1985 and 1994.[3] In this expanding population of adult CF patients, despite chronic and acute bacterial respiratory infections usually remain predominant, the frequency of isolation of fungi from the respiratory tract is increased compared with childhood. However, the related clinical manifestations are very heterogeneous, ranging from asymptomatic colonization to chronic infections, allergic disorders, or invasive diseases in immunosuppressed CF patients after lung transplantation.

In this narrative review, mainly addressed to clinicians without expertise in CF who may nonetheless encounter adult CF patients presenting with acute and chronic respiratory syndromes, we briefly summarize the most representative clinical aspects of respiratory fungal diseases in adult CF patients.

Methods

A MEDLINE/PubMed search was conducted in January 2019, inductively employing various combinations of the keywords "adult," "cystic fibrosis," "fung*," "respiratory infection," "aspergill*," and "ABPA." The full-text of retrieved papers was then reviewed and collectively discussed, with the decision about references to be included in the present narrative review being ultimately based on the subjective impression of the authors. For readers interested in an extended, in-depth description of specific clinical and pathogenetic aspects, which is beyond the scope of this article, some comprehensive reviews have been published in the past few years.[4-13]

Aspergillus spp

Aspergillus spp. are among the most widespread filamentous fungi in the environment, especially in areas with high humidity.[14] In CF patients, the most frequently isolated species is *Aspergillus fumigatus*, accounting for 67%-73% of *Aspergillus*-positive sputum cultures.[15] Isolation of other species such as *A. flavus*, *A. niger*, and *A. terreus* is less frequent but not rare (4%, 4%, and 2% of *Aspergillus*-positive sputum cultures, respectively).[15] Notably, the prevalence of isolation of *Aspergillus* spp. from sputum cultures in CF patients increases with age, possibly reaching 46%-78% in adult CF patients, although with important interregion and intercenter variability.[16-18]

However, knowledge of the prevalence of *Aspergillus* spp. isolation from sputum does not automatically allow to infer the prevalence of the various *Aspergillus*-related manifestations in CF patients, which range from asymptomatic colonization to invasive diseases (especially in lung transplant recipients). In this regard, Baxter at al[19] have proposed a classification based not only on sputum cultures but also on real-time polymerase chain reaction (RT-PCR) for *Aspergillus*, sputum level of galactomannan (a cellwall component of *Aspergillus*), total IgE, specific *A. fumigatus* IgE, and specific *A. fumigatus* IgG. This classification was developed by latent class analysis in triazole-naive patients, for ultimately creating a diagnostic algorithm specific for adult CF patients.[19] According to Baxter et al's[19] classification, adult CF patients may be divided into four classes with respect to *Aspergillus*-related diseases: (Class 1) nondiseased patients; (Class 2) allergic bronchopulmonary aspergillosis (ABPA); (Class 3) IgE-sensitized

Table 1. Simplified classification of *Aspergillus* spp. diseases in adult cystic fibrosis patients, based on the categories proposed by Baxter et al.[19]

CLASS	RT-PCR *ASPERGILLUS* (SPUTUM)	TOTAL IGE	SPECIFIC IGE FOR *A. FUMIGATUS*	SPECIFIC IGG FOR *A. FUMIGATUS*	GM LEVEL (SPUTUM)
Class 1: no disease	+/−	Normal	Normal	Normal	−
Class 2: ABPA	+	Increased	Increased	Increased	+
Class 3: *Aspergillus* sensitized	+/−	Increased (less than in ABPA)	Increased (less than in ABPA)	Normal	−
Class 4: *Aspergillus* bronchitis	+	Normal	Normal	Increased	+

Abbreviations: RT-PCR, real-time polymerase chain reaction; IgE, immunoglobulin E; IgG, immunoglobulin G; GM, galactomannan; ABPA, allergic bronchopulmonary aspergillosis. Simplified from Baxter et al.[19] Accurate diagnostic algorithms, together with sensitivity and specificity of the different cutoffs of the various markers, are available in the original publication.[19]
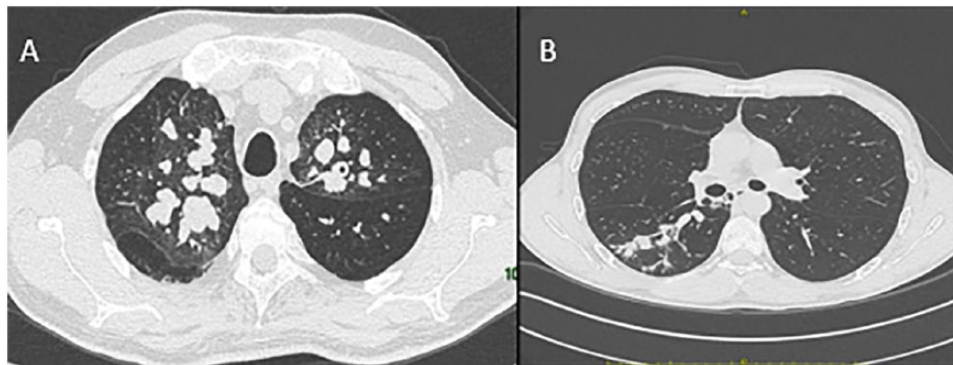
Figure 1. (A) Bilateral bronchiectasis with mucoid plugs in a 55-year-old male patient with cystic fibrosis and allergic bronchopulmonary aspergillosis (ABPA). (B) Monolateral pseudonodular infiltrates in a 41-year-old male patient with ABPA and a mild form of *Aspergillus* bronchitis triggering a diagnostic workflow ultimately leading to a late diagnosis of cystic fibrosis.

patients; (Class 4) *Aspergillus* airway infection or "bronchitis." A simplified representation of Baxter's classification is displayed in Table 1, whereas some examples of computerized tomography (CT) and bronchoscopy images of adult CF patients with *Aspergillus*-related diseases are shown in Figures 1 and 2.

Nondiseased patients

Notably, nondiseased patients may also include those subjects in whom *Aspergillus* spp. is isolated from sputum cultures in the presence of negative sputum galactomannan and no measurable immunological response to *Aspergillus* spp.[19] These patients could be defined as nondiseased patients with *Aspergillus* colonization, although it should be acknowledged that no standardized definition exists for *Aspergillus* colonization in CF patients. In any case, it seems that in these patients, the isolation of *Aspergillus* spp. is not associated with increased risks of pulmonary exacerbation, a more rapid decline of pulmonary function, and development of other *Aspergillus*-related diseases in comparison with noncolonized nondiseased patients,[20] and treatment of colonization is currently not recommended.[21]

Allergic bronchopulmonary aspergillosis

Allergic bronchopulmonary aspergillosis refers to a complex hypersensitivity reaction which often occurs in patients affected

Figure 2. Bronchoscopy of a 41-year-old cystic fibrosis patient with allergic bronchopulmonary aspergillosis and *Aspergillus* bronchitis; a dense mucoid plug is responsible for obstruction of the apical segmental bronchus of the right lower lobe.

by CF or asthma.[22] Allergic bronchopulmonary aspergillosis is the most common *Aspergillus*-related syndrome in CF, with prevalence ranging from 3% to 25% and being more common in adult than in pediatric CF patients.[20,23]

The clinical presentation of ABPA is heterogeneous, ranging from acute symptoms such as dyspnea, chest pain, wheezing, and/or productive cough with blackish sputum to more subtle forms with progressive reduction of forced expiratory volume in one second (FEV1).[24-26] Non-specific symptoms such as fever and myalgias may also coexist.[24-26] Respiratory function tests often identify airflow obstruction, while chest radiographic imaging could show parenchymal infiltrates that disappear a few days after starting steroid therapy. According to Baxter et al's[19] criteria, the diagnosis of ABPA is serological and can be made in the presence of positive sputum galactomannan, high serum IgE levels in the absence of steroid therapy, presence of specific IgG to *A. fumigatus*. The classical presentation of ABPA also included eosinophilia and immediate positive skin test for *A. fumigatus*.[27]

The treatment of ABPA is aimed at the attenuation of the immune response, which is usually achieved by corticosteroid therapy.[28] However, the association with azole antifungals, albeit remaining somewhat controversial, is not uncommon and aimed to contain the antigenic burden and minimize the exposure to steroid therapy.[28]

Aspergillus sensitization

Aspergillus sensitization is frequent in CF patients (up to 35% of cases) and is defined by the presence of elevated serum levels of specific IgE for *A. fumigatus* and slightly elevated total IgE independent of the presence of a positive culture or RT-PCR for *Aspergillus* spp.[19] According to immunological studies, sputum galactomannan is usually negative, with also low levels of *Aspergillus*-specific IgG.[19]

Notably, *Aspergillus* sensitization is considered as a pre-ABPA condition, as it reflects a predisposition to developing an immunological reaction in the absence of the pertinent antigen/s.[19] Differently from colonization in nondiseased patients, sensitization may be associated with lung function decline and increased frequency of pulmonary exacerbations.[29] However, as to whether *Aspergillus* sensitization should be treated for ameliorating symptoms and/or reducing lung function decline in CF patients remains controversial due to the absence of convincing evidence. Against this backdrop, a prudent wait-and-see approach based on symptoms and careful evaluation for alterations of respiratory function and biochemical signs (e.g. yearly evaluation of total serum IgE levels) has been suggested by some authors to reduce unwarranted pharmacological treatment.[22,30-32]

Aspergillus bronchitis

In CF patients, the disease-related progressive damage of the lungs may favor the development of chronic *Aspergillus* infection, commonly defined as "*Aspergillus* bronchitis," although aspergilloma(s) might also develop in some cases, especially in preexisting cavities or bronchiectasis.[33-35] *Aspergillus* bronchitis has an estimated prevalence of ~2% to 8% in CF patients and

may be suspected in the case of pulmonary exacerbation unresponsive to antibacterial treatment.[36,37] According to Baxter et al's[19] classification, diagnosis of *Aspergillus* bronchitis can be made in the presence of a positive sputum galactomannan, high levels of *Aspergillus*-specific IgG, and negative total and *Aspergillus*-specific IgE.

Since *Aspergillus* bronchitis does reflect infection and not an immune-mediated response as in ABPA, corticosteroids are not used for treatment. Treatment with azole derivatives is the current standard of care, although the overall duration of treatment is still not univocal.[28]

Invasive aspergillosis

Invasive aspergillosis is observed when the infection progresses across tissues and invades the vessels, with subsequent necrosis.[38] Usually, invasive aspergillosis is observed in severely-immunocompromised non-CF populations, such as hematology patients with prolonged neutropenia and patients receiving high dosages of corticosteroids or other immunosuppressant agents. Patients commonly report fever, chest pain, shortness of breath, and/or cough.[38] Hemoptysis and pneumothorax might also develop in some cases.[39,40] Invasive aspergillosis is rarely seen in patients affected by CF. However, it could develop in end-stage CF patient in intensive care units and in immunosuppressed CF patients after lung transplant, frequently in the form of *Aspergillus* tracheobronchitis, occurring mainly in the first 3 months after transplants and associated with high mortality (39%).[41,42]

Frequent symptoms of *Aspergillus* tracheobronchitis are severe dyspnea, cough, and wheezing.[28] The histopathological examination may show different features: (1) obstructive bronchial aspergillosis; (2) ulcerative tracheobronchitis (characterized by the invasion of the tracheobronchial mucosa and cartilage); (3) pseudomembranous tracheobronchitis (characterized by inflammation and invasion of the tracheobronchial tree). Invasive aspergillosis is usually treated with systemic azole therapy (possibly associated with nebulized amphotericin B in some cases of tracheobronchitis).[28] The U.S. guidelines recommend a minimum of 6 to 12 weeks of therapy for patients with invasive pulmonary aspergillosis, and at least 3 months in case of *Aspergillus* tracheobronchitis.[28]

Scedosporium apiospermium Complex

The *Scedosporium apiospermium* complex comprises three human pathogenic species: *Scedosporium apiospermium sensu strictu*, *Scedosporium boydii*, and *Scedosporium aurantiacum*.[43] Other species have been rarely associated with human disease.[44]

These filamentous fungi are ubiquitous and are mainly found in soil, polluted waters, and sewage.[45] They are the second most prevalent filamentous fungi isolated from the respiratory tract of CF patients, with the prevalence ranging from 0.7% to 9%.[44,46,47] However, the clinical significance of isolating *S. apiospermium* complex from the respiratory tract of CF patients is still a matter of debate.

In most cases, the contact with the host results in asymptomatic colonization, which can be either transient or permanent.[44] Colonization of the airways by *S. apiospermium* complex occurs more frequently in adolescents and adults than in children with CF, and often later than colonization by *Aspergillus* spp.[47]

Although colonization is the most frequently encountered situation, some cases of *S. apiospermium*-related disease have been described. Cimon at al[48] reported on two cases of allergic bronchopulmonary mycoses (ABPM) linked to this organism, resolved after combination treatment with itraconazole and oral corticosteroids. Other similar reports have prompted the suggestion by some authors to implement a regular screening for ABPM in patients colonized by *S. apiospermium* complex.[47]

S. apiospermium complex has also been reported to possibly cause invasive, disseminated disease in immunocompromised CF patients after lung transplantation. For example, Symoens et al[49] reported on a patient colonized in the pretransplant period who developed a postoperative *S. apiospermium* infection characterized by moderate fever, subcutaneous nodules, and bilateral chorioretinitis, with subsequent complete loss of vision, meningeal involvement and unfavorable outcome. *S. apiospermium* was isolated from both vitreous humor and cerebrospinal fluid.[49] Considering the reported low susceptibility of *S. apiospermium* complex to polyenes, azoles are usually employed as first-line therapy.[50]

Lomentospora prolificans

Formerly known as *Scedosporium prolificans*, this mold has much in common with its ex-cospecies, in terms of epidemiology and pathogenicity, although it greatly differs in terms of antifungal susceptibility, being resistant to amphotericin B, flucytosine, most azoles, and echinocandins.[51] This mold has a certain geographical distribution, being more frequently isolated in Australia, Northern Spain, and in the United States, although isolation from the respiratory tract of CF has also been reported in other countries such as Germany.[52-54]

As observed for other molds, *Lomentospora prolificans* usually causes transient or permanent colonization of the respiratory tract of CF patients, but an invasive disease with high mortality (>65%) may develop in a state of severe immunosuppression, with some centers considering isolation of *L. prolificans* as a possible contraindication to transplantation,[10,55,56] due to its multidrug-resistant profile.

Various regimens with available antifungals have been used in patients with invasive *L. prolificans* infection, frequently with unsatisfactory results.[57] Novel antifungals with possible activity against *L. prolificans* are under study.[58-61]

Exophiala dermatitidis

Exophiala dermatitidis is a thermophilic black yeast that grows as a filamentous fungus at room temperature. It is found in plant debris and soil in open environments, as well as in moist and hot environments such as bathrooms, saunas, and dish washers in closed environments.[44] Its prevalence as a colonizer of the respiratory tract in CF patients is not well defined, ranging from 1% to 15% in current literature.[62,63]

Its clinical significance remains uncertain, although recently Kondori et al[64] demonstrated the presence of serum IgG specific for *E. dermatitidis* in colonized CF patients, with inflammation markers being higher than those observed in patients without specific serum IgG. In colonized CF patients with severe respiratory symptoms not responding to antibiotic therapy, some authors have suggested that treatment with antifungals and clearance of *E. dermatitidis* from the sputum may be associated with an improvement in clinical conditions, but this possibility has yet to be confirmed. Voriconazole and posaconazole are usually active against this fungus.[65]

Candida spp

The prevalence of isolation of *Candida* yeasts from the respiratory tract of adult CF patients may be as high as to 93%, making it the most commonly isolated fungus in this population.[66] Prolonged use of antibiotic therapy seems to be one of the main factors associated with *Candida* spp. isolation.[67] *Candida albicans* is the most common isolated species in CF patients, although non-negligible frequencies of *C. dubliniensis, C. glabrata, C. parapsilosis*, and *C. tropicalis* have also been reported.[66,68,69]

Candida spp. may cause transient and permanent colonization of the respiratory tract of CF patients, but also oral and genital candidosis.[67] Furthermore, the development of candidemia during acute pulmonary exacerbation has been reported in central-venous devices carriers, including some severe cases.[70,71]

Although some authors have suggested that respiratory *Candida* colonization could be associated with a long-term decrease in FEV1 overtime, its role as a respiratory pathogen remains uncertain, and the presence of other agents/causes should always be investigated/suspected in the presence of respiratory symptoms.[72]

Other Fungi

The lung microbiome of CF patients comprises various permanent and transient fungi, whose growth and interactions are influenced by multiple factors, for example, antibiotic therapy.[73] In this complex environment, the isolation of many other fungi (e.g. *Pneumocystis jirovecii, Malassezia* spp., *Clavispora* spp., *Paecilomyces* spp., *Rasamsonia* spp., *Alternaria* spp., *Cladosporium* spp., *Penicillium* spp., *Trichosporon* spp., and *Talaromyces* spp.) has been described in the literature.[74] Although their clinical significance remains uncertain, noteworthy is that *Rasamsonia argillacea, Trichosporon* spp., and a few others have been possibly associated with long-term declines in lung function, and with invasive diseases after lung transplantation.[75-77]

Conclusions

The true burden of fungal disease in CF remains largely unknown. Chronic respiratory infection and acute pulmonary

exacerbations caused by different bacteria, together with the possible overlap of clinical and radiological features of bacterial and fungal diseases, might interfere with both diagnosis and follow-up of fungal diseases in adult CF patients.

The classification of *Aspergillus* diseases proposed by Baxter is certainly useful, but it should be kept in mind that it might not always be applicable in clinical practice, owing to logistic and technical reasons, such as the the unavailability of specific *A. fumigatus* IgG in many centers, and the nonunivocal interpretation of nonstandardized methods such as PCR and sputum galactomannan. Of note, the diagnostic role of another fungal antigen, (1,3)-β-D-glucan (BDG), is uncertain in CF patients,[78,79] although the detection of positive BDG levels in the blood of patients with a consistent clinical picture may be of help for the diagnosis of candidemia, as in other patient populations.[80,81]

Furthermore, different forms of fungal diseases might overlap (e.g. ABPA and *Aspergillus* bronchitis), interfering with a clear classification and standard treatment protocols. This is not a rare situation, since the isolation of molds in adult CF patients is more frequent than in childhood.

Following the advent of cystic fibrosis transmembrane conductance regulator (CFTR) modulators (ivacaftor, lumacaftor, and tezacaftor), drug interactions between these novel agents and azole antifungals have been reported, that may require strict therapeutic drug monitoring.[66] Whether or not the reduction of airway inflammation following the use of CFTR modulators could impact the development or the progression of fungal diseases in CF patients deserves further investigation.[82,83]

Notably, the increase in *A. fumigatus* resistance to azoles[84,85] might also complicate the therapeutic approach to *Aspergillus* diseases in CF patients, especially in adults, in whom they are expected to be more prevalent.

Finally, there is a need for standardized processing of respiratory specimens, as well as for repeated cultures over time (both because of possible suboptimal sensitivity and for differentiating between transient and chronic isolation).[11,36]

In conclusion, an updated knowledge of fungal respiratory diseases in adult CF patients can be of help for prompting an adequate early diagnostic and therapeutic workflow, as well as for referral to specialized centers for completion of all the necessary diagnostic procedures and the adequate management of immediate therapy and follow up.

Author Contributions

All the authors contributed equally to the writing of the manuscript. In addition, ED and DRG provided critical revision for intellectual content, and oversight. All the authors approved the final version of the manuscript.

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