Aspergillus fumigatus Allergen I, a Major IgE-binding Protein, Is a Member of the Mitogillin Family of Cytotoxins

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Summary

A major 18-kD IgE-binding protein from Aspergillus fumigatus (Asp f 1) has been purified. Partial amino acid sequencing of Asp f 1 showed extensive sequence homology (95%) between Asp f 1 and a cytotoxin (mitogillin) produced by A. restrictus. Crossinhibition radioimmunoassay using murine monoclonal antibody and human IgG and IgE antibodies showed that Asp f 1 and mitogillin were antigenically indistinguishable. Furthermore, both proteins inhibited protein synthesis in vitro by >90%. Asp f 1 was expressed in A. fumigatus but not in seven other Aspergillus species. The results suggest that Asp f 1 could play a dual role in the pathogenesis of A. fumigatus-related diseases by promoting colonization through cytotoxic activity and by causing inflammatory reactions involving IgE antibodies.

A spergillus fumigatus causes a diverse spectrum of human diseases, including allergic bronchopulmonary aspergillosis (ABPA), asthma, aspergilloma, and invasive infection in immunocompromised hosts (1). The respiratory tract of patients with chronic pulmonary diseases, particularly cystic fibrosis (2, 3), is frequently colonized by A. fumigatus. However, despite the ability of the fungus to cause tissue invasion, respiratory colonization by A. fumigatus is often regarded as saprophytic or benign. Serologic studies have shown that coloni zation can induce IgG and/or IgE antibodies to several A. fumigatus antigens (4-7), however, the structure and function of these antigens are largely unknown. In this report, we describe the purification of an 18-kD IgE-binding protein from A. fumigatus (Asp f 1) that is selectively expressed in A. fumigatus. Structural, functional, and antigenic analyses show that Asp f 1 is a member of the mitogillin family of cytotoxins (8, 9).

Materials and Methods

Purification of Asp f 1. A. fumigatus culture (30 g, strain no. 5167; Greer Laboratories, Lenoir, NC) was extracted overnight in 300 ml borate-buffered saline, pH 8.0 (BBS), and centrifuged (20,200 g, 30 min). A. fumigatus antigens were partially purified from the supernate by gel filtration and phenyl-Sepharose chromatography. A panel of six murine IgG1 mAbs was raised against an 18-kD, 2 M NaCl phenyl-Sepharose fraction. mAb 4A6 showed the highest binding to the 18-kD 2 M fraction in RIA and recognized an 18-kD protein. This protein, Asp f 1, was purified by affinity chromatography over mAb 4A6 immunosorbent followed by size exclusion HPLC using a Sepharose 12 HR 10/30 column (Pharmacia Fine Chemicals, Piscataway, NJ). The yield was 16-mg Asp f 1. Purity was assessed by SDS-PAGE using an 8-25% gel on a PhastSystem (Pharmacia Fine Chemicals).

Amino Acid Sequencing. 100 pg Asp f 1 was reduced and alkylated using 0.5% (vol/vol) 2-ME and 4% (vol/vol) vinyl pyridine and injected onto a reverse-phase HPLC column (C8; Brownlee Labs, Santa Clara, CA). The NH2-terminal amino acid sequence (27 residues) of the HPLC peak was determined using a gas phase sequencer (477-A; Applied Biosystems, Inc., Foster City, CA). Four tryptic peptides (T1, residues 22-28; T2, 29-38; T3, 43-60; and T4, 121-128) were sequenced as single sharp peaks from a reverse-phase HPLC column (C18; Applied Biosystems, Inc.) ACNBr fragment was also sequenced (residues 87-107).

IgE Antibody Assays. mAb 4A6 was used in a solid-phase RIA to present Asp f 1 to IgE antibodies. Bound IgE antibodies were detected by the addition of 2 ng affinity-purified, 125I-labeled goat anti-human IgE. Specific IgE antibody to Asp f 1 or to mitogillin was also determined by double antibody antigen-binding RIA (10). IgE antibody to A. fumigatus was measured by quantitative radioallergosorbent test (RAST) (11).

Crossinhibition RIA. Serial fourfold or 10-fold dilutions of cold Asp f 1 or mitogillin were incubated for 2 h with 60 ng mAb 4A6 or with 0.1 ml 1/4 or 1/25 dilution of serum from a patient with ABPA (J.H.) for the IgE and IgG assays, respectively. Subsequently, 6 ng of 125I Asp f 1 or 4 ng 125I mitogillin was added for 2 h, and antigen-antibody complexes were precipitated overnight using monospecific goat or sheep antisera (10). Precipitates were washed with BBS and counted in a gamma counter.

Inhibition of Protein Synthesis. Asp f 1 and mitogillin were used to inhibit protein synthesis in a rabbit reticulocyte lysate in vitro translation system for Brome Mosaic Virus (Promega Biotec, Madison, WI).
AspfI or mitogillin was added at 0.3–80 ng/ml in 7 µl RNAase-free distilled water. Total 35S-methionine incorporation (TCA precipitable counts) was determined by adding 7 µl distilled water only, and a reaction mixture containing no BMV-mRNA was used to determine background counts.

**Human Sera and Skin Testing.** Sera were obtained from six nonallergic control subjects and from 46 patients who had either positive immediate skin tests or serum IgE antibodies to *A. fumigatus* and clinical symptoms of ABPA (n = 14), cystic fibrosis and ABPA (n = 21), or asthma (n = 11). Intradermal skin tests were carried out using serial 10-fold dilutions of Asp fI, from 10–10^{-6} µg/ml (10).

**Results and Discussion**

We initially raised a mAb (clone 4A6) against partially purified *A. fumigatus* antigen and found that it recognized a single 18-kD band on immunoprecipitation. The mAb was used in a solid-phase RIA to present the antigen to human IgE antibodies. Of 13 patients with ABPA or asthma and positive serum IgE antibodies to *A. fumigatus* (RAST > 200 U/ml), 11 (85%) had IgE antibodies to the 18-kD antigen.

Patients with equivocal or weakly positive *A. fumigatus* RAST (n = 10; geometric mean, 29.5 U/ml) had no detectable IgE antibody. These results showed that the 18-kD antigen defined by mAb 4A6 was an important allergen. The allergen was purified by affinity chromatography and size exclusion HPLC (Fig. 1 A) and has provisionally been designated Asp fI. Partial amino acid sequencing of Asp fI showed extensive sequence homology (95%) between Asp fI and mitogillin, a cytotoxin produced by *A. restrictus* (Fig. 1 B). Mitogillin is a member of a family of cytotoxins that includes α-sarcin and restrictocin, produced by *A. giganteus* and *A. restrictus*, respectively. These cytotoxins are potent inhibitors of protein synthesis and act by cleaving the 3' end of the large RNA from the 60S ribosomal subunit (9). Mitogillin also causes regression of murine and canine tumors in vivo (12). Linear regression analysis showed an excellent quantitative correlation between IgE antibodies to Asp fI and to mitogillin (Fig. 2). On immediate skin testing, four of five patients with positive prick tests to *A. fumigatus* gave positive intradermal skin tests (> 6 x 6-mm wheal) to Asp fI at 10^{-2}–10^{-6} µg/ml. In contrast, two patients with positive skin tests to other allergens, but not to *A. fumigatus*, and four nonatopic controls, gave negative skin tests to 10 µg/ml Asp fI.

We investigated the antigenic and functional relationships between Asp fI and mitogillin by cross-inhibition RIA and by inhibition of cell-free protein synthesis in vitro. Superimposable, dose-dependent inhibition curves were obtained using cold Asp fI or mitogillin to inhibit the binding of either 125I-labeled proteins to mAb 4A6 or to human IgG or IgE antibody (Fig. 3). This effect was species specific in that extracts of seven other *Aspergillus* species, representative of distinct classification groups of the *Aspergilli* (13), caused <10% inhibition. Together, these results showed that Asp fI and mitogillin were antigenically indistinguishable. Using rabbit reticulocyte lysate to synthesize Brome Mosaic Virus protein, we observed >90% inhibition of protein synthesis by both mitogillin and Asp fI at concentrations of <20 ng/ml (Table 1).
1). Inhibition of protein synthesis by either molecule was not blocked by mAb 4A6, suggesting that the epitope recognized by mAb 4A6 is not located near the active site for ribosomal cleavage (Table 1).

*A. fumigatus* is the most common member of the genus *Aspergillus* that is associated with human disease, however, the reasons why *A. fumigatus* frequently colonizes the lungs are poorly understood (14, 15). Cytotoxic metabolites of *A. fumigatus* (e.g., gliotoxin and fumagillin) are thought to facilitate fungal growth by inhibiting macrophage function and causing immunosuppression (15, 16). Unlike *Asp f 1*, none of the low molecular weight metabolites induce IgE anti-

Table 1. *Asp f 1* and Mitogillin Inhibit In Vitro Protein Synthesis

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>Asp f 1 incorporation (percent inhibition)</th>
<th>Mitogillin incorporation (percent inhibition)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>cpm x 10³</td>
<td>cpm x 10³</td>
</tr>
<tr>
<td>80.0 ng/ml</td>
<td>22.7 (96.0)</td>
<td>22.9 (96.3)</td>
</tr>
<tr>
<td>20.0 ng/ml</td>
<td>35.9 (92.2)</td>
<td>30.0 (94.6)</td>
</tr>
<tr>
<td>5.0 ng/ml</td>
<td>236.1 (64.9)</td>
<td>38.4 (92.8)</td>
</tr>
<tr>
<td>1.2 ng/ml</td>
<td>613.9 (~6.2)</td>
<td>42.9 (91.9)</td>
</tr>
<tr>
<td>0.3 ng/ml</td>
<td>417.3 (4.3)</td>
<td>175.0 (68.7)</td>
</tr>
<tr>
<td>20 μg/ml inhibitor + 500 μg/ml mAb 4A6</td>
<td>9.1 (97.7)</td>
<td>8.1 (98.2)</td>
</tr>
<tr>
<td>Background (no mRNA)</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>Uninhibited positive control</td>
<td>545.2</td>
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Serial fourfold dilutions of either *Asp f 1* or mitogillin were used to inhibit incorporation of ³⁵S-methionine in an in vitro translation system for BMV protein. Incorporation of ³⁵S-methionine into protein was determined by TCA precipitation, and the results are expressed as cpm incorporated (x 10³). In addition, for each reaction, TCA precipitable counts were divided by the total counts added, and the percentage inhibition of the acid precipitable counts as compared with uninhibited controls is shown in parentheses. The estimated dose for 50% inhibition was 4 ng/ml for *Asp f 1* and 0.25 ng/ml for mitogillin. In a parallel experiment, we included the major cat allergen, *Fel d 1*, at 20 μg/ml, as a negative control and observed <2% inhibition of protein synthesis.
body formation. Mitogillin(s) were not previously known to occur in pathogenic *Aspergillus*, nor to cause IgE antibody responses, although, interestingly, hypersensitivity reactions (anaphylaxis and skin rashes) hampered U.S. trials of mitogillin in cancer chemotherapy (Dr. Ted Watson, personal communication; see also reference 12). Our results suggest that *Asp f 1* could play a dual role in the pathogenesis of *A. fumigatus*-related diseases by promoting fungal colonization through cytotoxic activity and by causing inflammatory reactions involving IgE antibodies present on human lung mast cells. Cytotoxic damage to the respiratory mucosa would be expected to be augmented by the production of IgE anti-*Asp f 1* antibodies, which occur in most sera from patients with ABPA and cystic fibrosis. *Asp f 1* was not detected in other pathogenic *Aspergillus* species. Thus, the selective expression of *Asp f 1* in *A. fumigatus* could be a virulence factor that aids the growth of this fungus in man, in addition to its small spore size and ability to proliferate at human body temperature (13). It will now be possible to investigate this hypothesis and the immunobiologic role of *Asp f 1* in *A. fumigatus*-related diseases.

We thank Dr. Robert Esch for providing *A. fumigatus* culture extract; Dr. Ted Watson for providing purified mitogillin; and Drs. Joan Longbottom, Jane El-Dahr, and George Ward for providing sera from patients with ABPA and cystic fibrosis. We are also grateful to Dr. Shu Man Fu for his critical review of the manuscript.

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