Effect of the implosion and demolition of a hospital building on the concentration of fungi in the air

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Summary
Building renovations increase the concentration of Aspergillus conidia in the air. In 2010, one wing of the hospital building was imploded due to structural problems. To evaluate the impact of building implosion on the concentration of fungi in the air, the demolition was performed in two phases: mechanical demolition of 30 m of the building, followed by implosion of the wing. Patients at high risk for aspergillosis were placed in protected wards. Air sampling was performed during mechanical demolition, on the day of implosion and after implosion. Total and specific fungal concentrations were compared in the different areas and periods of sampling, using the ANOVA test. The incidence of IA in the year before and after implosion was calculated. The mean concentration of Aspergillus increased during mechanical demolition and on the day of implosion. However, in the most protected areas, there was no significant difference in the concentration of fungi. The incidence of invasive aspergillosis (cases per 1000 admissions) was 0.9 in the 12 months before, 0.4 during, and 0.5 in the 12 months after mechanical demolition (P > 0.05). Continuous monitoring of the quality of air and effective infection control measures are important to minimize the impact of building demolition.

Key words: Building, implosion, Aspergillus, airborne fungi, infection control.

Introduction
The association between higher concentrations of Aspergillus in the air and the occurrence of invasive aspergillosis (IA) is well recognised.¹ High concentrations of Aspergillus conidia are typically present during building constructions and renovations,² and recommendations to minimise the exposure of high-risk patients to environments with high concentrations of conidia have been developed, including the use of rooms with high efficiency particulate air (HEPA) filters.³

The Hospital Universitário Clementino Fraga Filho (HUCFF) is a tertiary care hospital affiliated to the Federal University of Rio de Janeiro. The hospital building had two "T" shaped wings, but only one wing was occupied. In 2010 structural problems in concrete pilings that supported the building foundation were detected in the non-occupied wing. As a consequence, demolition of this wing was planned in two phases: first, mechanical demolition of 30 m of the non-occupied T-wing to detach the two wings; and second, implosion of the wing. The objective of this study was to evaluate the impact of mechanical demolition and subsequent implosion of the wing on the concentration of fungi inside and outside the hospital.

Materials and methods
This study was conducted between August 2010 and October 2013. The manual detachment of the two
wings (mechanical demolition) started on August 2010 and ended in November 2010. After this procedure, all patients were removed to other hospitals by the end of November 2010, and the implosion took place on December 19, 2010. The hospital was reopened for patients in February 2011. Air sampling was performed during the mechanical demolition period, on the day of implosion (30 min before, and 5, 15, 35, 65 and 95 min after) and after the implosion. In addition, we used data from a historical period (2004 and 2007–2009), when periodic sampling of the air had been performed (following the same procedures as between 2010 and 2013).

During the mechanical demolition to detach the two wings, the following measures were implemented by the Infection Control Service of the hospital to minimize exposure: permanent humidification of the location of demolition by constant blasting of water during demolition, limitation of circulation of people in areas close to the demolition, sealing of the windows of some hospital wards, increase in environmental cleaning, periodic (at least once a month) monitoring of the quality of air and staff education. Patients were divided into three risk groups and placed in more protected areas if they were classified in the higher risk groups. Patients with acute leukaemia and recipients of haematopoietic cell transplantation were considered the highest risk to develop invasive aspergillosis, and were cared in rooms with HEPA filters. Patients with HIV in advanced stages, patients receiving high doses of corticosteroids or other immunosuppressive agents and solid organ transplant recipients were considered at intermediate risk, and were cared in sealed rooms without HEPA filters. All other patients were considered at low risk. In addition, high-risk patients used N95 masks when they circulated in non-protected areas.

Air samples were collected using a 6-stage Andersen air sampler (Andersen; Thermo Fisher Scientific, Inc. Waltham, MA, USA), which collects air at a rate of 28.3 l min\(^{-1}\). Each stage of the air sampler was filled with 90 × 15 mm plates containing 2% Sabouraud dextrose agar (DIFCO, Houston, Texas, USA) with gentamycin (200 µg ml\(^{-1}\)). The samples were performed during 30 min in indoor areas and 5 min in outdoor areas. After sampling, the plates were incubated at 25 °C for at least 7 days. Colony counts were performed weekly, and subcultures were made using potato-dextrose agar (DIFCO), agar Czapek (DIFCO), lactrimel agar, oat agar and malt extract agar. Identification of fungi was performed on the basis of morphological parameters, initially by observing the characteristics of colonies in a stereoscopic microscope. Subcultures were performed if the colonies had the characteristics consistent with clinically relevant fungi (Aspergillus, Fusarium, agents of mucormycosis, as well as Cladosporium and Penicillium).

In order to analyse the concentration of fungi, we classified the hospital areas in four categories, according to the level of environmental protection: air corridors and open wards (six-bed patients’ wards with wide opened windows), one- or two-bed rooms without filters, operating rooms and intensive care unit, and single-bed rooms with HEPA filters and positive pressure. We also reviewed records of the mycology laboratory, radiology and pathology to search for cases of invasive aspergillosis before, during and after the demolition.

The mean total and specific fungal concentrations, expressed as colony-forming units per cubic metre of air (CFU per m\(^3\)), were compared using one-way analysis of variance (ANOVA). The chi-square test was used to compare the proportion between groups. \(P\) values <0.05 were considered statistically significant. All analyses were performed using the (SPSS IBM, Armonk, NY, USA) software, version 15.0.

**Results**

During the study period, 127 air samples were collected and processed: 38 during the mechanical demolition (detachment of the two wings), six on the day of implosion (30 min before, and 5, 20, 35, 65 and 95 min after the implosion) and 83 after the implosion, including to the level of environmental protection: air corridors and open wards (six-bed patients’ wards with wide opened windows), one- or two-bed rooms without filters, operating rooms and intensive care unit, and single-bed rooms with HEPA filters and positive pressure. We also reviewed records of the mycology laboratory, radiology and pathology to search for cases of invasive aspergillosis before, during and after the demolition.

The mean total and specific fungal concentrations, expressed as colony-forming units per cubic metre of air (CFU per m\(^3\)), were compared using one-way analysis of variance (ANOVA). The chi-square test was used to compare the proportion between groups. \(P\) values <0.05 were considered statistically significant. All analyses were performed using the (SPSS IBM, Armonk, NY, USA) software, version 15.0.

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During the study period, 127 air samples were collected and processed: 38 during the mechanical demolition (detachment of the two wings), six on the day of implosion (30 min before, and 5, 20, 35, 65 and 95 min after the implosion) and 83 after the implosion, from 2011 to 2013. In addition, the results of 91 air samples performed in the historical period (30 in 2004, 24 in 2007, and 37 in 2009) were analysed for a total of 218 air samples. Figure 1 shows a map of the building with the location of the samplings. Figure 2 shows the mechanical demolition to detach the two wings and Fig. 3 shows the implosion of the wing.

The mean concentration of fungi in the 218 air samples was 526.71 CFU m\(^{-3}\) of air (SD 1181.59). As shown in Fig. 4, the mean concentration of fungi increased during mechanical demolition compared with the historical period. The concentration increased even more on the day of implosion, with values of 148.17 CFU m\(^{-3}\) in the historical period, 271.45 CFU m\(^{-3}\) during demolition, 1887.67 CFU on the day of implosion and 204.10 CFU m\(^{-3}\) in the postimplosion period (\(P < 0.001\)). The mean temperature during air sampling was 25.8 °C (SD 3.78) and the mean air humidity was 70.3% (SD 13.0). The
The mean concentration of fungi in each of the six stages of the air sampler were: 6.59 CFU m\(^{-3}\) in stage 1, 8.84 CFU m\(^{-3}\) in stage 2, 27.07 CFU m\(^{-3}\) in stage 3, 53.03 CFU m\(^{-3}\) in stage 4, 40.88 CFU m\(^{-3}\) in stage 5, and 2.47 CFU m\(^{-3}\) in stage 6.

Hyaline fungi without identification to genus represented 32% of fungi in the whole period. The most frequent genus was *Cladosporium* spp. (27% of fungi, with a mean of 45.09 CFU m\(^{-3}\) of air), followed by *Penicillium* spp. (12% of all fungi, mean 14.35 CFU m\(^{-3}\)) and *Aspergillus* spp. (6% of fungi, mean 9.22 CFU m\(^{-3}\)).

*Aspergillus* spp. grew from 62.6% of all air samples in the historical period, 68.4% in the mechanical demolition period, 83.3% on the day of implosion (only external air), and 77.1% in the postimplosion period (\(P = 0.18\)). On the other hand, the concentration of *Aspergillus* spp. in these periods varied significantly: 3.71 CFU m\(^{-3}\) of air in the historical period, 7.18 CFU m\(^{-3}\) in the mechanical demolition period, 22.5 CFU m\(^{-3}\) on the day of implosion, and 15.13 CFU m\(^{-3}\) of air in the postimplosion period (\(P = 0.001\)). The most frequent species was *Aspergillus niger* (29% in the historical period, 9% in the mechanical demolition period, 41% on the day of implosion, and 38% in the postimplosion period), followed by *A. fumigatus*. However, the majority of *Aspergillus* isolates was not identified at species level.

*Fusarium* spp. grew from 15.4% of air samples in the historical period, 2.6% in the mechanical demolition period, zero on the day of implosion, and 1.2% in the postimplosion period (\(P = 0.002\)). The mean concentration of agents of mucormycosis was low in all periods (0.2 CFU m\(^{-3}\) of air in the historical period, zero in the periods of mechanical demolition and implosion and 0.1 CFU m\(^{-3}\) of air in the postimplosion period). Dematiaceous fungi other than *Cladosporium* spp. were encountered in small amounts (mean 3.45 CFU m\(^{-3}\) of air).
Figure 5 shows the concentration of fungi on the day of implosion. There was a sharp increase in the concentration immediately after the implosion (3624 CFU m\(^{-3}\) of air 5 min after compared with 170 CFU m\(^{-3}\) of air 30 min before). The concentration decreased in the subsequent samples, to a value of 1191 CFU m\(^{-3}\) of air 95 min after the implosion.

The proportion of the different fungi in the study period is shown in Fig. 6. Hyaline fungi without identification of genus represented >90% of fungi found in the air on the day of implosion, and remained high in the postimplosion period.

Table 1 shows the concentration of fungi in different areas of the hospital before and after the implosion. In the air corridors and open wards (the areas most exposed to the external air), the concentration of fungi was significantly higher in the mechanical demolition period. However, in the more protected areas, the difference in fungal concentration was not statistically significant. On the other hand, in the 1- or 2-bed rooms without filters, there was a significant increase in the concentration of *Aspergillus* spp. comparing the historical period (4.72 CFU m\(^{-3}\) of air), period of mechanical demolition (17.33 UFC m\(^{-3}\)), and the postimplosion period (32.50 CFU m\(^{-3}\)). The same was observed regarding the concentration of hyaline fungi. In the protected areas of the operating room and intensive care unit, the differences in the concentration of fungi were not statistically significant. Finally, in the rooms with HEPA filters, the only significant difference was in the concentration of hyaline fungi, with a higher concentration in the historical period and low concentration in the mechanical demolition and postimplosion periods.
The incidence of invasive aspergillosis (cases per 1000 admissions) was 0.9 in the 12 months before mechanical demolition, 0.4 during mechanical demolition and 0.5 in the 12 months after implosion ($P > 0.05$).

**Discussion**

In this study, we observed that the implosion resulted in a great increase in the concentration of fungi in the air. Likewise, the mechanical demolition of part of the building (manual detachment of the two wings) was associated with an increase in the concentration of fungi. This increase was observed with all fungi, as well as with *Aspergillus* species. We also observed that the concentration of *Fusarium* spp. was higher in the historical period, and that after the implosion hyaline fungi predominated. Finally, the incidence of IA did not increase during the period of manual detachment of the two hospital wings.

The association between outbreaks of IA and activities related to building constructions and demolitions close to the hospital is well known. This is not a surprise, since these building activities are associated with an increase in the concentration of fungal spores in the air. Therefore, preventative measures aiming at decreasing the exposure of high-risk patients to these environments are recommended.

The concentration of fungi in the air in periods of building constructions and renovations has been evaluated in various studies. Bouza et al. [10] observed a significant increase in the concentration of fungal spores immediately after the implosion of a building. A similar observation was made in this study: compared with historical period, there was a significant increase in the concentration of fungi in the air during demolition and even higher just after the implosion. The same trend was observed for *Aspergillus* spp. Streifel et al. [13] also observed an increase in the concentration of *Aspergillus* and other thermo-tolerant fungi after the implosion of a hospital building, with high concentrations of *A. fumigatus* and *A. flavus*. By contrast, *A. niger* and *A. flavus* were the most prevalent species in the studies conducted by Cornet et al. [14] and Srinvasan et al. [12]. In this study, *A. niger* was the most frequent species, but our data are limited by the fact that species identification was not performed in most *Aspergillus* isolates recovered from the air.

In this study, the concentration of *Fusarium* spp. presented a different pattern as compared with that of *Aspergillus* spp., with a higher concentration in the historical period. This is of great interest because in the same institution it was observed an increase in the incidence of invasive fusariosis beginning in 2007, with most of the patients presenting a cutaneous portal of entry. Similarly, the authors reported an increase in the recovery of *Fusarium* spp. from skin lesions of immunocompetent individuals from the dermatology outpatient clinic. Furthermore, genetic studies of *Fusarium* isolates recovered from the

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**Figure 5** Fungal counts on the day of implosion.

**Figure 6** Proportion of fungi in the air in the different periods.
hospital and from patients showed a great genotypic diversity, indication that the cases originated from the community rather than the hospital.\textsuperscript{17}

\textit{Fusarium} is widely found in the environment, and is a pathogen of various plants, including tomato, soybean and other grains.\textsuperscript{18} One possibility for an increase in \textit{Fusarium} in the environment is agricultural activities. For example, the Cerrado area is a large (~2 million m\textsuperscript{2}) territory in Brazil. Over the past 15–20 years, the area suffered a great change in its composition, with a massive replacement of the native vegetation with soybean and pasture.\textsuperscript{19} The fungal diversity in these areas is much lower compared with the native vegetation.\textsuperscript{20} The confirmation of these hypotheses needs further studies.

Interestingly, hyaline fungi without identification to genus increased were greatly represented throughout the study period (32%), increased on the day of implosion (~90%), and remained high in the postimplosion period (43%). Unfortunately since most of these fungi did not exhibit sporulation, identification to genus was not possible, hampering further comments about the epidemiology of these fungi. Molecular methods should have been undertaken in order to identify these fungi. Of interest was the high concentration of these hyaline fungi in the historical period. These findings may reflect lower standards in the maintenance of these facilities during the historical period, compared with the more critical periods (mechanical demolition and postimplosion), when more adhesion to standards may have occurred.

While \textit{Cladosporium} spp. and \textit{Alternaria} spp. are frequently found in the environment throughout the world,\textsuperscript{21} \textit{Alternaria} was very uncommon in our study (<1%), with \textit{Cladosporium} (27%), \textit{Penicillium} (12%) and \textit{Aspergillus} (6%) being the most frequent fungi recovered from the air. Comparisons between different studies are difficult because of different standards and equipment for air sampling.\textsuperscript{14}

In this study, the incidence of IA did not increase during the period of manual detachment of the two hospital wings. As shown in Table 1, the concentration of \textit{Aspergillus} in protected areas of the hospital (rooms with HEPA filters) did not differ during the study period. Therefore, it is reasonable to state that the measure of selecting these areas to patients at high risk to develop IA was successful. However, it must be acknowledged that a clear-cut correlation between the concentration of fungi in the environment and cases of IA has not been consistently shown.\textsuperscript{22} Likewise, there is no consensus about what should be considered a ‘normal’ concentration of fungi in the hospital.\textsuperscript{23–25}

### Table 1: Concentration of fungi in the different areas of the hospital before and after demolition.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Cladosporium</th>
<th>Penicillium</th>
<th>Aspergillus</th>
<th>Fusarium</th>
<th>Hyaline fungi\textsuperscript{1}</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air corridors and open wards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical period</td>
<td>180.64</td>
<td>24.73 (28)</td>
<td>12.96 (17)</td>
<td>0.67 (2)</td>
<td>0.39</td>
<td>18.91 (23)</td>
</tr>
<tr>
<td>Demolition period</td>
<td>1023.50</td>
<td>82.31 (21)</td>
<td>21.21 (5)</td>
<td>3.83 (0.8)</td>
<td>0</td>
<td>30.44 (9)</td>
</tr>
<tr>
<td>Postimplosion period</td>
<td>226.95</td>
<td>31.36 (19)</td>
<td>15.51 (8)</td>
<td>17.47 (8)</td>
<td>0.05</td>
<td>83.50 (43)</td>
</tr>
<tr>
<td>(P) value</td>
<td>0.002</td>
<td>0.15</td>
<td>0.91</td>
<td>0.13</td>
<td>0.21</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Rooms without filters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical period</td>
<td>123.62</td>
<td>74.79 (48)</td>
<td>19.25 (17)</td>
<td>4.72 (4)</td>
<td>0.68</td>
<td>14.32 (18)</td>
</tr>
<tr>
<td>Demolition period</td>
<td>212.08</td>
<td>47.31 (28)</td>
<td>31.11 (16)</td>
<td>17.33 (6)</td>
<td>0</td>
<td>30.42 (16)</td>
</tr>
<tr>
<td>Postimplosion period</td>
<td>152.83</td>
<td>26.01 (26)</td>
<td>18.35 (11)</td>
<td>32.50 (17)</td>
<td>0.08</td>
<td>62.38 (38)</td>
</tr>
<tr>
<td>(P) value</td>
<td>0.16</td>
<td>0.23</td>
<td>0.51</td>
<td>0.02</td>
<td>0.54</td>
<td>0.01</td>
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<tr>
<td><strong>Operating room and ICU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical period</td>
<td>114.60</td>
<td>18.14 (19)</td>
<td>16.61 (18)</td>
<td>13.90 (11)</td>
<td>0.40</td>
<td>21.79 (23)</td>
</tr>
<tr>
<td>Demolition period</td>
<td>124.67</td>
<td>9.62 (26)</td>
<td>8.05 (8)</td>
<td>3.33 (9)</td>
<td>0</td>
<td>9.42 (15)</td>
</tr>
<tr>
<td>Postimplosion period</td>
<td>84.91</td>
<td>47.43 (16)</td>
<td>9.42 (27)</td>
<td>5.50 (11)</td>
<td>0.09</td>
<td>15.26 (31)</td>
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<tr>
<td>(P) value</td>
<td>0.81</td>
<td>0.77</td>
<td>0.09</td>
<td>0.14</td>
<td>0.18</td>
<td>0.38</td>
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<td><strong>Rooms with HEPA filters</strong></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Historical period</td>
<td>113.81</td>
<td>10.89 (26)</td>
<td>10.67 (10)</td>
<td>0.59 (1)</td>
<td>0.06</td>
<td>88.70 (54)</td>
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<td>Demolition period</td>
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<td>7.31 (29)</td>
<td>1.43 (2)</td>
<td>1.57 (11)</td>
<td>0.07</td>
<td>1.51 (7)</td>
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<tr>
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<td>8.50</td>
<td>1.47 (10)</td>
<td>2.65 (23)</td>
<td>0.25 (3)</td>
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<td>2.65 (55)</td>
</tr>
<tr>
<td>(P) value</td>
<td>0.14</td>
<td>0.57</td>
<td>0.48</td>
<td>0.16</td>
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<td>0.03</td>
</tr>
</tbody>
</table>

\textsuperscript{1}hyaline molds, not specified.

ICU, intensive care unit; HEPA, high efficiency particulate air.
In summary, our study showed that the implosion of the building resulted in a great increase in the concentration of fungi in the air. The mechanical demolition also resulted in an increase in the concentration of fungi in the hospital, but this was restricted to the less protected areas. The incidence of IA did not increase during mechanical demolition, probably due to the strict control measures taken to reduce the dispersal and exposure of the fungal conidia to the patients.

Conflict of interest
The authors have no conflicts of interest related to the contents of this article.

References