Biofilm-Forming Capability of Highly Virulent, Multidrug-Resistant Candida auris

Leighann Sherry, Gordon Ramage, Ryan Kean, Andrew Borman, Elizabeth M. Johnson, Malcolm D. Richardson, Riina Rautemaa-Richardson

The emerging multidrug-resistant yeast pathogen Candida auris has attracted considerable attention as a source of healthcare-associated infections. We report that this highly virulent yeast has the capacity to form antifungal resistant biofilms sensitive to the disinfectant chlorhexidine in vitro.

The yeast pathogen Candida auris was first detected in 2009 from an ear canal infection in Japan (1). This species initially attracted attention because of its reduced susceptibility to azoles and amphotericin B, combined with the lack of reliable culture-based methods for its identification (2). More recently, C. auris has been associated globally with life-threatening invasive diseases, such as bloodstream and wound infections. C. auris has also caused hospital outbreaks across Asia and South America, as highlighted in a 2016 clinical alert (3). In addition, in a UK intensive care unit, candidemia developed in 20% of patients colonized with C. auris (4). Although the mode of transmission within hospitals is unknown, C. auris may substantially contaminate rooms of colonized or infected patients (5). Phospholipase and proteinase activity have been identified as virulence factors (6); however, because previously used assessment techniques were rudimentary, this pathogen’s ability to form biofilm remains under question (7). The draft genome identifying various proteins involved in biofilm formation (8), coupled with recent descriptions of aggregative and nonaggregative phenotypes, the latter of which are more virulent in vivo (9), indicate the possibility of heterogeneous C. auris biofilm formation, as described for C. albicans (10). We sought to examine these aggregative and nonaggregative C. auris phenotypes in the context of biofilm-forming capacity, investigate their susceptibility to a panel of antifungal agents and the skin disinfectant chlorhexidine, and investigate their virulence in vivo.

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The Study

Throughout this study, we used C. albicans SC5314 and Candida glabrata WT2001 as comparators for C. auris nonaggregative strains NCPF 8971 (strain 10) and NCPF 8973 (strain 12) and aggregative strains NCPF 8977 (strain 2) and NCPF 8978 (strain 6), as previously described (9). Strains were propagated in YPD broth (Sigma-Aldrich, Dorset, UK), incubated overnight at 30°C, and adjusted to 10^6 cells/mL in RPMI 1640 medium (11). On 3 separate occasions, 8 biofilms of each Candida species were grown in flat-bottomed, 96-well polystyrene microtiter plates and incubated for 24 h at 37°C, after which biomass was assessed by crystal violet assay (12). C. albicans displayed the greatest biofilm mass (Figure 1, panel A), consistent with previous findings (10). Compared with C. albicans, all C. auris strains formed significantly reduced biofilms (p<0.0001): biomass for nonaggregative C. auris strains 10 and 12 was 2.4 and 1.5 times less, respectively, than those for C. albicans, and biomass for aggregative C. auris strains 2 and 6 was 3.0 and 3.1 times less, respectively. However, these strains formed significantly greater biofilms (p<0.0001) than those formed by C. glabrata (3.8, 6.0, 3.0, and 2.9 times more for strains 10, 12, 2, and 6, respectively). We confirmed these findings for each species by scanning electron microscopy after growing the strains on Thermanox Coverslips (Thermo Fisher Scientific, Paisley, UK) for 24 h, as previously described (12). C. albicans biofilms were typically densely packed with hyphae (Figure 1, panel B), whereas C. glabrata formed a sparse biofilm consisting of yeast cells only, without extracellular matrix (Figure 1, panel C). C. auris strain 10 biofilm formation was intermediate to the C. albicans and C. glabrata phenotypes, showing predominately budding yeast and occasional pseudohyphae (Figure 1, panel D). In agreement with previous findings (9), all tested C. auris strains displayed the same phenotype.

To determine MICs for planktonic and sessile cells of the C. auris strains, we performed antifungal susceptibility testing using standardized Clinical Laboratory Standards Institute M27-A3 broth microdilution (visual inspection) and standardized candidal biofilm testing (metabolic viability) with fluconazole, voriconazole, caspofungin, micafungin, liposomal amphotericin B, amphotericin B, and chlorhexidine (13,14). Antifungal agents were tested in serial 2-fold dilutions (0.06–32.0 mg/L) for planktonic and sessile cells. Fluconazole was ineffective (MICs of >32 mg/L) against planktonic and sessile communities, whereas...
voriconazole displayed minimal activity against planktonic cells (Table 1, 2). Although liposomal amphotericin B was active against planktonic $C. \text{auris}$ at 0.25–1.0 mg/L, up to 16 mg/L was required to kill biofilms. Micafungin was the most active echinocandin, requiring <0.5 mg/L to inhibit planktonic cells, compared with 2–32 mg/L for caspofungin. However, these 2 antifungal agents were ineffective against biofilms, requiring >32 mg/L to inhibit sessile cells. Of note, chlorhexidine exhibited the greatest activity, requiring <0.02% to effectively inhibit planktonic and sessile cells across all strains tested. All strains showed similar sensitivity profiles, with the exception of strain 10, for which voriconazole was required in higher concentrations and caspofungin in lower concentrations to effectively inhibit planktonic growth.

Killing assays in $Galleria \text{mellonella}$ were performed, as previously described (12), to assess the pathogenicity of each $Candida$ species. Ten $G. \text{mellonella}$ larvae (Livefoods Direct Ltd, Sheffield, UK) with bodyweights of ≈300 mg were used for each test group. Standardized inoculums of $10^6$ and $10^5$ and to $5 \times 10^5$ and $5 \times 10^4$ cells/larvae (Figure 2) in PBS, were injected into the hemocoel, as previously described (9). We assessed pathogenicity using a Kaplan-Meier plot, monitoring the percent survival over 5 days. Survival data for $5 \times 10^5$ cells/larvae showed a significant difference in the killing of larvae by $C. \text{glabrata}$ and the other $Candida$ species (p<0.0001) (Figure 2, panel B). Although $C. \text{albicans}$ and $C. \text{auris}$ had similar kill kinetics in this model, infection with nonaggregative $C. \text{auris}$ strain 10 achieved a 100% death rate within 48 h, compared with a rate of ≈87% with $C. \text{albicans}$ (p = 0.3076). Moreover,

Table 1. Planktonic susceptibility profiles of 7 antifungals against $Candida \text{auris}$ yeast

<table>
<thead>
<tr>
<th>Drug</th>
<th>Strain 2</th>
<th>Strain 6</th>
<th>Strain 10</th>
<th>Strain 12</th>
</tr>
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<tbody>
<tr>
<td>Fluconazole</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Voriconazole</td>
<td>8</td>
<td>8</td>
<td>32</td>
<td>1</td>
</tr>
<tr>
<td>Caspofungin</td>
<td>32</td>
<td>32</td>
<td>2</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Micafungin</td>
<td>0.5</td>
<td>≤0.0625</td>
<td>&lt;0.06</td>
<td>≤0.0625</td>
</tr>
<tr>
<td>Liposomal amphotericin B</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Amphotericin B</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Chlorhexidine, %</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

*Values are mg/L except as indicated. All MIC tests were performed on 3 independent occasions, showing identical results each time.
nonaggregative C. auris was significantly more pathogenic than C. albicans when a lower inoculum of 10^5 (p<0.05) and 5 × 10^4 cells/larvae (p<0.01) was administered. These data, along with those of Borman et al. (9), suggest that the nonaggregative C. auris phenotype has the capacity to form biofilms with enhanced virulence capacity.

Conclusions
Biofilm formation is a key driver of C. albicans pathogenicity and is associated with patient death (10,15). We show that C. auris can differentially adhere to polymeric surfaces, form biofilms, and resist antifungal agents that are active against its planktonic counterparts. Of particular interest, caspofungin was predominately inactive against C. auris biofilms; this finding was unexpected because caspofungin is normally highly effective against Candida biofilms. These features contribute not only to C. auris virulence but also to its survival in hospital environments, increasing its ability to cause outbreaks (5). The results of the in vivo model used in this study are in line with our clinical experience and validated by findings in other in vivo studies (9), affirming that C. auris is highly virulent or more virulent than C. albicans.

Although unable to form biofilms equivalent to C. albicans, C. auris has a noteworthy virulence capacity that merits further exploration, particularly given the apparent heterogeneity associated with aggregative capacity. These factors, together with the innate resistance of C. auris to most antifungal agents, may explain why it is an emerging pathogen. Our findings suggest it is improbable that the spread and prevalence of C. auris can be controlled with antifungal stewardship approaches alone. We showed that chlorhexidine is effective against C. auris planktonic and sessile communities. Thus, use of this disinfectant can be advocated for topical control of C. auris at standard concentrations used for skin and wound cleansing and disinfection (0.05%–4.0%). Infection-prevention measures targeting C. auris biofilms in patients, on medical devices (e.g., equipment in contact with patients), and in the hospital environment will be required.

Table 2. Sessile susceptibility profiles of 7 antifungals against Candida auris yeast

<table>
<thead>
<tr>
<th>Drug</th>
<th>Strain 2 Sessile MIC*</th>
<th>Strain 6 Sessile MIC*</th>
<th>Strain 10 Sessile MIC</th>
<th>Strain 12 Sessile MIC</th>
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<tr>
<td>Fluconazole</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
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<tr>
<td>Voriconazole</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Caspofungin</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Micafungin</td>
<td>&gt;32</td>
<td>0.25</td>
<td>&gt;32</td>
<td>&gt;32</td>
</tr>
<tr>
<td>Liposomal amphotericin B</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Amphotericin B</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Chlorhexidine, %</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

*Values indicate mg/L except as indicated. Sessile MICs are defined as a 90% inhibition of the metabolic dye XTT, 2,3-Bis(2-methoxy-4-nitro-5-sulfophenyl)-2H-tetrazolium-5-carboxanilide inner salt (Sigma-Aldrich, Dorset, UK) compared with the untreated control; MIC tests were performed on 3 independent occasions and showed identical results each time.

Figure 2. Pathogenicity of Candida species yeast infections in vivo. Galleria mellonella larvae were infected with 10^6 (A), 5 × 10^6 (B), 10^6 (C), and 5 × 10^4 (D) cells/larvae of C. albicans, C. glabrata, and 4 C. auris strains, and larvae survival measured every 12 h over 5 d. Ten samples of each yeast were used, and experiments were performed on 3 independent occasions. Data represents the mean percentage survival, as determined using a Kaplan-Meier plot. PBS and controls, which were pierced only, were also included and had no effect on larvae survival. Results show that C. auris and C. albicans infection exhibit similar pathogenicity.
Dr. Sherry works as a medical mycologist at the University of Glasgow, Glasgow, UK. Her specific interest is fungal biofilms of clinical significance.

References


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EID Podcast: Lives of a Cell: 40 Years Later, A Third Interpretation

In 1974, Lewis Thomas (1913–1993), physician, professor, and dean, published The Lives of A Cell, the first of 2 books subtitled Notes of a Biology Watcher. The phrase “lives of a cell” refers to the independent yet interconnected parts of a human cell—including mitochondria, centrioles, and basal bodies—that once led independent lives. Without these previously independent lives working together, we would not have the capacity for thought, communication, and movement. Dr. Thomas wrote, “Our membranes hold against equilibrium, maintain imbalance, bank against entropy… We are shared, rent and occupied.”

Our human lives do not depend just on the lives in our individual cells. Our lives depend fully on the earth, including the atmosphere, and the many other human and nonhuman lives that occupy it. In explaining this complex interdependence, Dr. Thomas observed that the earth is “most like a cell.” This second interpretation of lives of a cell refers to the many interconnected earthly entities, such as plants, whales, humans, and even viruses, that “dart rather like bees from organism to organism, from plant to insect to mammal to me and back again,” all protected by the sky—a membrane that “works, and for what it is designed to accomplish it is as infallible as anything in nature.”

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