Study of Bioaerosols in Surgical Theaters and Intensive Care Units from a Public General Hospital

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Abstract: The health of building occupants may be affected by bioaerosols, particularly aerosolized bacteria and fungi. We determined airborne bacteria and fungi in 31 settings from a public general hospital. Air samples were taken by the impaction method on solid surface. Microbial identification was run by standard microbiological techniques. Results were interpreted by the criteria from The Spanish Association of Hospital Engineering and Canadian Health and Wealth Department. Results showed microbial density values ranging from 1 UFC/m$^3$ to 222 UFC/m$^3$. In general, bacteria in surgical and non-surgical settings were within the “clean” range. However, the Oto-rhino M2 surgery room, D surgery room and the Nephrology surgery room exceeded the non-contaminated range. The Sterilization room and the Neonatal intensive care unit also depicted bacteria and fungi contamination, respectively. Coagulase-positive Staphylococcus was found in the Traumatology J surgery room and in the Urology S1 surgery room, while Serratia marcescens was isolated in the Nephrology surgery room. Therefore, J and S1 surgery rooms were also considered contaminated regardless of their low bacterial count. Bacterial identification revealed 14 genera and 8 species, being coagulase-negative Staphylococcus the most frequent bacterial isolate. The majority of the locations showed fungal densities values within the “very clean” and “clean” ranges, showing the isolation of 12 genera and 5 species. Aspegillus and Penicillum spp. were the most frequent fungal isolates. The indoor air microbiological quality in white theaters was determined by a rapid cultured-based method and a combination of indoor air microbiological quality criteria.

KEYWORDS: Air quality, bioaerosols, BRI, white theaters

Indoor air may be responsible for signs and symptoms that building occupants experience when they are exposed to combination of biological (bioaerosols), chemical and physical factors. Consequently, indoor air quality is a major concern when considering the health hazards related to the habitability of many buildings. When building occupants experience any or many unspecific severe health and comfort signs and symptoms, which appears to be correlated to the period of exposure inside a ”sick building” rather than to a particular illness or cause, then such conditions are known by the term Sick Building Syndrome. Usually, signs and symptoms tend to disappear as occupants abandon the sick building, but return when they get back. However, the SBS may worsen in time and establish a permanent clinical condition in occupants (1). According to the U. S. Environmental Protection Agency (EPA) signs and symptoms usually consists of headache, eye, nose or throat irritation, dry cough, dry or itchy skin dizziness and nausea, difficulty in concentrating, fatigue and sensitivity to odors among others (2).

On the other hand, the term “Building Related Illness” (BRI) is more applicable to hospital environments and it is used to describe clinically identifiable illnesses experienced by building occupants exposed to specific airborne bacteria.
or fungi found in buildings. This becomes very relevant when building occupants are exposed patients in surgical theaters and intensive care units in hospital settings. Patients in operating rooms and intensive care units may be considered a special type of building occupant since they are inuncompromised persons whose body’s first line of defense is affected by such hospital settings. In addition, hospital environments tend to concentrate airborne pathogenic airborne bacteria and fungi, which increase the risk of biological hazards. Beyond the controversial security levels of bioaerosols in common indoor conditions, airborne bacteria and fungi in white theaters from hospital settings must be strictly controlled and kept in the lowest possible level in order to avoid postsurgical in infections.

Indoor air in surgery rooms usually become a source of post-surgery infection diseases. Similarly, the air in intensive care units offers a source of microbial contamination for both institutionalized patients and medical personal, which are frequently exposed to bioaerosols for a longer period of time in relation to occupants in surgery room environments. Consequently, indoor air from white areas in hospitals, particularly surgery rooms and intensive care units, must be regulated by strict cleanliness standards, regardless of the outdoor air quality. Cleanness protocols usually are applied to room infrastructure, medical and paramedical personal, surgery instruments, waste disposal and air. In this type of environment air may become a contaminant itself and, in addition, can act as a vehicle to disseminate bioaerosols originated from many sources.

In cases related to both SBS and BRI, indoor air quality may be affected by bioaerosol constituents, such as bacteria and fungi, and by chemical and physical factors, which mainly include total organic compounds, temperature, humidity and breathable particles.

Bioaerosols usually contain dead and viable bacteria, fungi, parasites, protozoan, algae, virus, and cell derivatives. In addition, dust particles and water drops are aerosolized together with microorganisms and other biological particles (3, 4). Accordingly, it is imperative that physical-chemical factors, such as those mentioned above, as well as the right influx of fresh air must be controlled inside buildings to reduce the density of bioaerosols (5). Also, the nature of the building materials is especially relevant to bioaerosol generation, particularly those used in the construction of heating, ventilating and air conditioning systems (HVAC), carpets, walls, ceilings and other products and structures.

Bioaerosols determination is not only a way to characterize the indoor air quality but also a mean of testing the effectiveness and efficiency of indoor air cleaning procedures (6, 7). Particularly, bacteria and fungi have proven to be the key bioaerosol constituents to be analyzed for indoor air quality assessment. To this effect several methods for bioaerosol trapping have been designed, which would allow the determination of microbial density as an indoor air quality index (8-11). Gravity, impregnation and impaction of bioaerosols on liquid and solid surfaces are the main physical principles upon which microbiological air sampler are based. From these, the impaction method is widely used for rapid and reliable microbial density determination.

Even though the use of microbial (bacteria and fungi) density for evaluating indoor air quality has not been included in legislation concerning occupational health standards, several health organizations have proposed different criteria for assessing indoor air quality depending on the nature of the indoor area, mainly for white areas in hospital environments and non-white areas in regular indoor rooms (12). For instance, in regard to non-white areas, the National Institute of Health and Occupational Wealth (NIOSH) has established that indoor areas with microbial density values ≥ 1000 CFU/m$^3$ would be considered contaminated. However, the American Conference of Governmental Industrial Hygienists (ACGIH) has reduced such value to 500 CFU/m$^3$ (13). The Department of Health and Wealth of Canada also proposed that fungi density should not be higher than 50-500 CFU/m$^3$ depending on the fungi genera and fungi homogeneity. The Department of Health of New York (NYHD) recognizes that security levels in terms of microbial density is hard to define, but indoor air evaluation should also considered microbial identification and outdoor air microbial density (14). The Spanish Association of Hospital Engineering (AEIH) has defined the following criteria for assessing indoor air quality in hospital environments (white areas): bacterial and fungal density values <10 CFU/m$^3$ ⇒ very clean, bacterial and fungal density values 10-100 CFU/m$^3$ ⇒ clean, bacterial and fungal density values 100-200 CFU/m$^3$ ⇒ acceptable and bacterial and fungal density values > 200 CFU/m$^3$ ⇒ contaminated (15).

In this study, we evaluated the indoor air quality in surgery rooms and intensive care units from the biggest Venezuelan general public hospital by the impaction method over solid surface in terms of the density and the pathogenic status of aerosolized bacteria and fungi.

Materials and Methods

Hospital Theater

A 1084 beds-public general hospital located in Caracas, Venezuela was selected due to its relevance as a national reference hospital and to its susceptibility to SBS and BRI.

Air sampling

Air samples were taken by the impaction method over a solid surface. For that purpose, we sampled 1000 l air within
a 10 min period using an Andersen 1 perforated platform type-
microbiological air sampler MAS-100 (Merck, Germany). This
device directs the air-stream onto the agar surface of standard
Ø 90 mm Petri dishes utilizing a suction pump. Airflow is con-
tinuously monitored and regulated to a constant flow of 100 L/
min at a speed of 11 m/s, allowing collecting up to 1000 L per
run. These properties equal the stage 5 in the typical six
stages Andersen-impactor.

Air Samples

Indoor air samples were collected from 24 surgery rooms,
2 auxiliary surgery rooms, and 5 intensive care units (white
areas) as follow:

Surgery rooms from: Gynecology (Q room), Urology (S1
room), Dermatology, Oto-rhino (M1 and M2 rooms), Ophthal-
mology (L1 and L2 rooms), Obstetrics, Traumatology (K, J
and M rooms), Cardiovascular (A and B rooms); Neurosurgery
(D room), Hemodynamics (H room), Pediatric (G room), Gen-
eral Surgery (C, E, F, I and P rooms), Nephrology, Surgery I
designed for bacterial growth while discouraging fungal growth
and fungi were used as the criteria for microbiological indoor
samples, the same were subjected to incubation conditions for a period of 2 days and 7 days, respectively. Microbial density
values were then determined in a colony counter (Darkfield
Quebec Colony Counter, Buffalo, NY, USA) after the comple-
tion of the incubation periods.

Incubation conditions for bacteria and fungi.

Bioaerosols trapped into the especially designed fungal
and bacterial culture media were incubated at 30°C and 37°C,
respectively. In order to determine the density values associ-
ated with bacteria and fungi present in each gathered air sam-
ple, concentrations of 20 mg/L.

Quantitative indoor air quality index for white areas

In accordance with the Spanish Association of Hospital
Engineering, the following microbiological quality index was
used in indoor air (Cruceta 2007):

- A. Bacterial and fungal density <10 CFU/m³ air ⇒ very
clean

- B. Bacterial and fungal density 10-100 CFU/m³ ⇒ clean

- C. Bacterial and fungal density 100-200 CFU/m³ ⇒ ac-
tceptable only for ambulatory and minor surgery

- D. Bacterial and fungal density > 200 CFU/m³ ⇒ con-
taminated

- E. Bacterial and fungal density > 10 CFU/m³ in organ

transplantation units ⇒ contaminated.

- F. Bacterial and fungal density > 1 CFU/m³ in bone marrow

transplantation unit ⇒ contaminated.

- G. Fungal density from a single fungal genera isolation >50

CFU/m³ air ⇒ contaminated

Qualitative indoor air quality index for white areas

Bacteria and fungi isolates were identified by standard
microbiological methods. The presence of pathogenic bacteria
and fungi were used as the criteria for microbiological indoor
air contamination as stated by the Department of Health and
Wealth of Canada.

Statistical analysis

Results were expressed as average CFU/m³ air from each
location. Student’s t test was used for statistical analysis.
Samples with P values < 0.05 were considered statistically
different. 
Results

In this study, indoor air quality was analyzed using the bacterial and fungal density as a microbiological quality index. Microbial identification was also taken into account for a complete microbial indoor air evaluation.

In regards to the environments studied, it was shown that bacterial density mostly ranged from 14 CFU/m^3 to 200 CFU/ m^3 (Figs. 1, 2, 5), suggesting that air was either in the clean or acceptable range, according to the criteria of the Spanish Association of Hospital Engineering. On average we found 4:1 bacteria: fungus ratio in surgery rooms (Figs. 1-4) and 2:1 bacteria: fungus ratio in non-surgery rooms (Fig. 5). Only Surgery II room depicted a predominant fungi population (60%) in relation to bacteria (40%) (Figs. 2, 4).

In contrast with most of the surgical theaters, the Otorhino M2 surgery room was found to have bacterial density values that exceeded the non-contaminated range adopted in this study (Fig. 2), depicted the highest average value of global suspended bacteria (222 CFU/m^3 air) and showed a significant bacterial count increase in relation to the rest of the surgical theaters (p < 0.05). In addition, the bacterial identification in the Oto-rhino M2 surgery room showed the highest bacteria diversity, from which Acinetobacter junni, Stenotrophomonas maltophilia, and coagulase-negative Staphylococcus were the relevant isolates (Table 1). Even though these bacteria species are not pathogens themselves, they behave as opportunistic pathogens, especially in operating room environments.

The nephrology surgery room, which is a kidney transplantation unit, depicted bacterial and fungal densities in the range 10-100 CFU/m^3 (Figs. 3, 4). Accordingly, this surgery room was also considered contaminated due to the nature of the surgical procedures that were undertaken in this area. The bacterial identification in this surgical theater showed the isolation of 3 bacterial genera, one of which was identified as Seratia marcescens, an occasional indoor air pathogen (Fig. 3, Table 1).
Despite the fact that the rest of the surgical theaters were found to have microbial density values consistent with the adopted “clean” range, some of them depicted the isolation of bacterial pathogens. Coagulase-positive *Staphylococcus* was found in the Traumatology J surgery room and in the Urology S1 surgery room (Fig 3, Table 1). Due to the presence of these bacterial pathogenic species (Table 1) these surgery rooms were also considered contaminated.

**Table 1:** Bacterial identification in contaminated and non-contaminated surgical and non-surgical theaters. *:* relevant theater.

<table>
<thead>
<tr>
<th>Isolated bacteria</th>
<th>White Theater (surgical and non-surgical locations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acinetobacter baumannii</td>
<td>G, H and Hand surgery</td>
</tr>
<tr>
<td>Acinetobacter lwooffii</td>
<td>P</td>
</tr>
<tr>
<td>Acinetobacter junii</td>
<td>M1, A, B, M2*</td>
</tr>
<tr>
<td>Bacillus subtilis</td>
<td>M1, F, A, L1, L2, obstetric, Dermatology, Gynecology, Surgery I, Surgery II, General ICU, Cardiovascular ICU, Neurosurgery ICU, ICU for neonatal surgery, Neonatal ICU, Sterilization of surgical instruments*, M2*</td>
</tr>
<tr>
<td>Lactobacillus spp.</td>
<td>K</td>
</tr>
<tr>
<td>Micrococcus spp.</td>
<td>P, M1, E, hand, Gynecology, Dermatology, Surgery I, Cardiovascular ICU, Sterilization of surgical instruments*, Nephrology*, S1*</td>
</tr>
<tr>
<td>Pseudomonas spp.</td>
<td>D, Neurosurgery ICU</td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>K, Surgery I</td>
</tr>
<tr>
<td>saprophyticus</td>
<td>M2*</td>
</tr>
<tr>
<td>Stenotrophomonas maltophilia</td>
<td>M2*</td>
</tr>
<tr>
<td>Coagulase-positive</td>
<td>J*, S1*</td>
</tr>
<tr>
<td><em>Staphylococcus</em></td>
<td></td>
</tr>
<tr>
<td><em>Serratia marcescens</em></td>
<td>Nephrology*</td>
</tr>
</tbody>
</table>

**Figure 4:** Indoor air fungal density of peripheral surgical locations. Surgical theaters were located in different floors away from the main surgical area.

**Figure 5:** Indoor air bacterial and fungal densities of non-surgical locations. Non-surgical theaters were located in different floors apart from the main and peripheral surgical areas.

In regard to the intensive care units and the two auxiliary surgery rooms (where the surgery instruments are sterilized and retained just prior to surgery), it was found that the sterilization room and the neonatal intensive care unit depicted bacterial and fungal density values significantly higher than the other non-surgical theaters (p < 0.05) and consistent with the adopted “contamination” range, respectively (Fig. 5). Furthermore, the sterilization room revealed, however, the presence of non-relevant bacterial isolates, such as *Bacillus* spp. and *Micrococcus* spp. (Table 1). The others non-surgical areas depicted bacterial and fungal density values within the adopted “acceptable” range (100-200 CFUm$^3$ air) and “clean” range 10-100 CFUm$^3$ air, respectively (Fig. 5).

The D surgery room (a general surgery room), and the Oto-rhino peripheral M1 surgery room registered bacterial density values in the range 100-200 UFC/m$^3$ air (Figs. 1 and 3, respectively). However, the bacterial density value in the M1 surgery room was not significant in terms of contamination values (p > 0.05). According to these results, only D surgery room was classified as contaminated because it depicted a bacterial density value only suitable for minor and ambulatory surgery. This room showed the presence of bacterial opportunistic pathogens (Table 1).

On the other hand, bacteria density values in the E, P, D, M1, Surgery I, general ICU and Neonatal ICU rooms depicted bacterial density values significantly above the average bacte-
ria density values found in the main, peripheral and non-surgical white theaters (p< 0.05). These results showed that even though some white locations depicted airborne bacteria within the clean range, they were overloaded in relation to their counterpart operating rooms.

In terms of bacteria diversity, the P room (general surgery), M1 room (Otorhinology service), K room (Traumatology service), and J room (Traumatology service), followed the M2 surgery room, each registering the isolation of 4 bacterial genera each (Table 1).

It is important to point out that the most common bacterial specie isolated from all white areas was coagulase-negative Staphylococcus, which was detected in 21 of the total 32 white theaters, followed by Bacillus subtilis, Micrococcus spp. and Corynebacterium spp., which were isolated in 18, 14 and 13 white theaters, respectively (Table 1). Contrary to these bacterial isolates, Stenotrophomas maltophilia, Staphylococcus saprophyticus, Acinetobacter iwooffi and Pseudomonas spp. were the least frequent bacterial species isolated from all locations (Table 1).

In all cases it was found that the non-surgical areas (intensive care units and auxiliary surgery rooms) showed significant higher bacterial counts than those found in the surgical theaters (p< 0.05). However, most of these theaters were still within the acceptable microbial density range, with no relevant variation in terms of bacteria diversity in relation to the operating rooms. Most abundant bacterial species in these theaters were coagulase-negative Staphylococcus and Bacillus subtilis. Nevertheless, the diversity of non-pathogenic, opportunistic and pathogenic bacteria found in this study was more restricted than others reported in the literature (16).

On the other hand, fungal density values ranged, in general, from 1 CFU/m³ air to 206 CFU/m³ (Figs. 2, 4, 5). Almost all surgery rooms depicted fungal density values in the range 1-10 CFU/m³ air (very clean), while L1, M, Obstetric, Q, S1, Surgery I and Dermatology surgery rooms from the Ophthalmology, Traumatology, Obstetric, Gynecology, Urology, Surgery I and Dermatology services, respectively, had fungal density values in the range 10-100 CFU/m³ air (clean). Surgery II room showed the highest fungal density value of all surgical areas (120 CFU/m³ air), depicting fungal counts only acceptable for minor and ambulatory surgery. In addition, the intensive care unit for Neonatal surgery (Fig. 5), a white but non-surgical theater, also depicted fungal contamination (206 CFU/m³ air), which was significantly higher than the fungal counts in the other white settings (p< 0.05). The fungi identification in this surgical theater revealed the presence of Penicillium spp., a SBS-associated-fungal genus (Table 2). The Nephrology surgery room registered a fungal density value of 22 CFU/m³ air, which surpassed the allowed fungal density value for transplantation units (Fig. 4). Fungi isolation in this area revealed the SBS-associated Aspergillus spp. and Aspergillus niger (Table 2). On the other hand, the fungal isolation in the M2 surgery room revealed the presence of Penicillium spp., Aspergillus spp. and Aspergillus niger (Table 2). These fungal microorganisms have been associated to the SBS and also behave as opportunistic pathogens directly or indirectly through mycotoxins in exposed patients under operating conditions.

Other relevant white theaters such as the J room, S1 room, and sterilization room revealed the presence of Aspergillus fumigates, Aspergillus niger and Penicillium spp., Aspergillus fumigates, Aspergillus niger and Fusarium spp., respectively (Table 2).

The Surgery II room, still within the allowed fungal limit, registered a fungi density value of 162 CFU/m³ air, 14 times the average fungal density value detected in the other surgery rooms and significantly higher than the other non-contaminated settings (p< 0.05). Fusarium spp, Penicillium spp. and various species of Aspergillus, all SBS-associated fungi, were isolated in this environment (Table 2).

The E, D, H, A and Surgery I theaters, which were found to have bacterial density values within the “clean-very clean” range, were also found to have fungi counts above average. These results were in clear contrast with those associated with their counterpart’s operating rooms. Contrary to the presence of bacterial pathogens found in the white areas (Table 1),

**Table 2: Fungal identification in contaminated and non-contaminated surgical and non-surgical theaters. *: relevant theater.**

<table>
<thead>
<tr>
<th>Isolated fungus</th>
<th>White Theater (surgical and non-surgical locations)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage of surgical instruments, General ICU, Cardiovascular ICU, Neurosurgery ICU, M2*, L1, ICU for Neonatal surgery, Obstetric, Neonatal ICU*</td>
</tr>
<tr>
<td>Aspergillus fumigates</td>
<td>P, C, G, H, K, J, Hand, Sterilization of surgical instruments*, J, M1, M1, L1, S1*</td>
</tr>
<tr>
<td>Aspergillus flavus</td>
<td>Surgery II, F, H, Neonatal ICU*</td>
</tr>
<tr>
<td>Aspergillus clavatus</td>
<td>Surgery I, Obstetric, Neonatal ICU*</td>
</tr>
<tr>
<td>Scedosporium spp.</td>
<td>Surgery I, Cardiovascular ICU, G</td>
</tr>
<tr>
<td>Fusarium spp.</td>
<td>Surgery II, E, C</td>
</tr>
<tr>
<td>Rhodotorula spp.</td>
<td>ICU for Neonatal surgery, G</td>
</tr>
<tr>
<td>Paecilomyces spp.</td>
<td>I</td>
</tr>
<tr>
<td>Aspergillus terreus</td>
<td>A</td>
</tr>
<tr>
<td>Curvularia spp.</td>
<td>M1</td>
</tr>
<tr>
<td>Trichoderma spp.</td>
<td>M1</td>
</tr>
<tr>
<td>Aspergillus spp.</td>
<td>Hand, Sterilization of surgical instruments, Nephrology*, M2*</td>
</tr>
<tr>
<td>Cladosporium spp.</td>
<td>Cardiovascular ICU</td>
</tr>
<tr>
<td>Alternaria spp.</td>
<td>Surgery I</td>
</tr>
</tbody>
</table>

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pathogenic fungi were not depicted in these locations (Table 2). However, 11 fungal genera and 5 fungal species were isolated, of which some were considered opportunistic pathogens or at least SBS-associated fungi. Scedosporium spp, Cladosporium spp, and Trichoderm spp were the least frequent fugal isolates, whereas Penicillium spp (21 isolates), Aspergillus niger (15 isolates) and Aspergillus fumi-gatus (13 isolates) were the most abundant fungi found in this hospital (Table 2). Furthermore, Aspergillus niger and Aspergillus fumi-gatus became the most common fungal species. Although these fungi, together with Fusarium and Scedosporium, are non-pathogenic microorganisms, they behave as opportunistic pathogens and have been associated with SBS and BRI in cases involving sensible and immune-compromised building occupants (17-19). Particularly, Aspergillus spp. and/or Penicillium spp. were detected in nearly all the white areas, with the exception of the cardiovascular surgery B room (Table 4). Surgery I registered the highest fungal diversity, with the isolation of 5 fungal genera, followed by Surgery II, Gynecology and M1 surgery room where 4 fungal genera were identified. Despite the fact such fungal genera are frequently found in this type of environment, fungal counts were much lower in this hospital than others counts reported in the literature (20).

Discussion

Surgery rooms and intensive care units are high risk locations for both patients and staffs. SBS and specially BRI can develop in these types of environments if indoor air is poorly controlled.

Threshold values or the minimum dose of airborne bacteria and fungi required to cause disease have not been national or internationally established for secure indoor air due to the fact that it has been very difficult to correlate microbial density with adverse side effects, particularly because these depend on the type of microorganism, the genetics and immunogenic conditions of the occupants as well the opportune medical care. However, some guidelines or recommendations have been proposed. Apart from these specific microbiological indexes, many researchers agree that bacteria and fungi densities in indoor air should at least be equal or lower than that found in outdoor air and, in addition, these environments should be free of pathogenic microorganisms, regardless of the microbial density (21). However, non pathogenic bacteria and fungi, which are normal environmental microorganisms, may become opportunistic in relation to vulnerable patient in operating conditions. On the other hand, pathogenic species lack safe limits and are unacceptable in any settings, especially in surgery theaters. In addition, when indoor air is considered in surgery settings and intensive care units, indoor air must meet a near sterile condition. In these cases, the threshold density values of bacteria and fungi for secure indoor air become more evident.

According to the data presented in this study, there was a potential transmission route in some surgery rooms for airborne opportunistic and pathogenic microorganisms to patients while being operated on. In relation to this type of environment, air quality management has to provide a very low indoor air microbial density, regardless of the incoming outdoor air quality. The basis of this is that patients who are being operated or patients kept in intensive care theaters have most of their natural body defenses temporarily affected by surgery or other type of trauma and hence, can be easily contaminated with even very low airborne microbial charges.

In this study, which is the first of this nature to be made in Venezuela, we investigated the microbiological indoor air quality of all surgical theaters and intensive care units from an important public general hospital in the capital city, which is responsible for managing a high percentage of patients coming from different regions of the country. In recognition of these relevant facts, we investigated two particular parameters of bioaerosols, that is, the density of viable and cultivable airborne bacteria and fungi, together with the identification of such microorganisms, in order to use such information as tools to determine the indoor air quality of such environments. In addition, a combination of suggested international criteria for a microbiological indoor air indexes were adopted in this study to interpret the data.

In general, our results showed that in terms of bacteria density values almost all surgical theaters were found to be within the “clean” range (10-100 CFU/m3 air), whereas the intensive care units depicted values within the “acceptable” range (100-200 CFU/m3 air). It was notorious that the peripheral and the main surgery rooms showed no significant difference in terms of bacterial counts, despite that a more strict cleaning protocol and staff control was observed in the main surgical settings. On the other hand, non-surgery white settings (intensive care units and others) indicated bacterial counts twice that found in the surgery rooms.

However, a rather peculiar result showed that the highest bacterial counts were found in the Oto-rhino M2 surgery room and Surgery I room, both peripheral surgery rooms located out of the main surgical area. In regard to the Oto-rhino M2 surgery room we speculate that the nasopharynx surgery activities taking place in this theater could have been an important source of bacterial contamination, whereas the Surgery I room was affected by a temporary HVAC failure that occurred several days before the air sampling. This is compelling evidence suggesting that the appropriate management of HVAC systems is critical to ensure the quality of indoor air (22). Another point of interest is related to the Nephrology surgery room, where patients are subjected to more powerful immune-depressed medications to prevent organ rejection. The results showed that this surgery room was affected by both a high microbial contamination, relative to other transplantation theaters, and the presence of pathogenic bacteria. This result could be explained by the fact that this surgery room is sub-
jectected to the same cleaning protocols and staff controls as other surgical theaters. This approach is incorrect because the Nephrology surgery room, being a transplantation theater, requires more strict surveillance in terms of sanitization and control of professional personal, which should be in full compliance with optimal microbial counts set to be substantially below the microbial counts expected in regular surgical theaters.

In contrast to the Oto-rhino M surgery room where bacterial contamination was found according to the adopted bacterial density range criteria, both the Traumatology J surgery room, and the Urology surgery room were considered contaminated based on the isolation of pathogenic bacteria. This study showed that unifying criteria including both microbial density and microbial identification can help to detect microbiological contamination in indoor air. It was striking to find that most surgery rooms depicted opportunistic bacteria, many of which have been associated with the Sick Building Syndrome and Building Related Illness. Although the presence of this type of microorganism was not used as a criterion of contamination, we believed that such findings should trigger a risk alert.

In regard to fungal density values, the study revealed, with few exceptions, that surgery rooms were within the “very clean” range, whereas the intensive care units depicted values within the “clean” range. These results were predicted from the found bacteria: fungus ratio in surgical and non-surgical rooms (4:1 and 2:1, respectively). These findings could be explained based on the fact that the surgery theaters were under a more strict cleaning protocol and staff control than the intensive care units.

It is interesting to note that the intensive care units and the two auxiliary surgery rooms depicted an increase of fungi in relation to bacteria as compared to the surgical rooms. We suggest that in operating rooms the patients themselves and the HVAC system became the main sources of bacterial contamination, whereas in the intensive care units and the auxiliary surgery rooms we found a diverse source for microbial contamination, such as patients, staffs, visitors, construction materials, HVAC system, equipments, humidity, cleanliness protocol, frequent bed linen changes and other conditions that could favor the presence of fungi (23). Contrary to the bacterial counts in both surgery room locations, peripheral surgery rooms depicted fungal counts 4 times higher than that found in the main surgery rooms. It was striking that surgery II room showed a fungal count around 10 times higher than that found in all surgery rooms, indicating the highest fungal contamination in any white setting. This result could not be explained on the general apparent conditions of this room, in contrast to the high bacteria count found in the surgery I room due to the HVAC system failure. Consequently, the basis of this finding remains unknown.

In contrast to the isolation of pathogenic bacteria in some white settings, only non-pathogenic, regular SBS-associated fungi were detected in this study. However, these fungi were of concern in surgery rooms and intensive care units due to the fact that they usually behave as opportunistic microorganisms in white environments. This result was very interesting based on the fact that aerosolized pathogenic fungi are not usually of concern in hospital settings.

In contrast to non-white areas, where we usually find immunocompetent occupants who could be affected by SBS, we showed that white areas, which were populated by susceptible institutionalized occupants, usually immunocompromised patients, were vulnerable to postsurgical infections as part of the “Building Related Illness” while still in the recuperative phase. Concurrently, medical staff and related personal servicing such areas could also suffer signs and symptoms commonly related to the “Sick Building Syndrome”.

After compiling the results of this study, we have found that the surgical and non-surgical areas, of the selected hospital, consistently reflected bacteria:fungus ratio of 4:1 and 2:1, respectively. These bacteria:fungi values, as they related to surgical rooms, were consistent with those reported previously (16, 20, 24-26), although the absolute bacteria and fungi counts were much higher in the referenced studies than in ours. These results, strongly supported by the existing literature, fundamentally stress the fact that, when analyzing hospitals indoor air, bacteria are found in more abundance than fungi. Nevertheless, this is not properly factor in the literature microbiological indoor air index, since both types of microorganisms are usually treated equally for the formulation of such index.

Based on our results, we then propose that, in order to study the indoor air quality of white areas in hospital settings, a fungal count criterion should be set to a value lower than that applicable to bacteria, so that the fungal index for indoor air contamination reflects the real proportion of this type of microorganism in the context of the bacteria:fungus ratio normally reported in the literature. However, more studies have to be done in order to establish that the fungi count level used in this study as a non-contamination criterion may be adversely affecting the health of patients and/or medical staff while present in these areas, so that the fact that the amount of fungi found should be considerable less than that of bacteria becomes a substantiated argument to support such proposition.

All our data took us to emphasize the premise that microbial density in white areas must be kept as near to a full sterility conditions as possible, regardless of the outdoor air quality. Consequently, we concluded that indoor amplification of bioaerosols from outdoor environments in non-white areas was irrelevant as a benchmark for room contamination in white areas.

**Conclusion**

From this study we concluded that the majority of the surgical facilities of the selected hospital should be considered to
be in “clean” to “very clean” condition. Few exceptions to this assessment were found. However, implementing more efficient indoor air managing procedures could mitigate the adverse finding to the point of compliance with establish indoor air quality standards.

The data generated from this study, the first of this nature to be conducted in Venezuela, demonstrated that the indoor air found in hospital environments can be evaluated to establish an early alert, rather than to determine a clear cut-health hazard situation, which could trigger opportune remediation procedures aimed to improve the general hospital conditions and used to avoid post surgical and post institutionalized patient contamination. We presented a culture-based sampling technique as a quick mean of characterizing the indoor air quality of airborne bacteria and fungi. We pretended to address a contribution to the study of the indoor air quality in Venezuela in the published literature, which we recognize has been negligible. We believe our results, in terms of microbial density and microbiota as a mean to evaluate indoor air quality in hospital settings, provide an advance in knowledge that can be generalized beyond the specific circumstances studied.

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