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Distribution Characteristics of Airborne Bacteria and Fungi in the General Hospitals of Korea

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Abstract: The objective of this study is to provide fundamental data related to size-based characteristics of bioaerosol distributed in the general hospital. Measurement sites are main lobby, ICU, surgical ward and biomedical laboratory and total five times were sampled with six-stage cascade impactor. Mean concentrations of airborne bacteria and fungi were the highest in main lobby as followed by an order of surgical ward, ICU and biomedical laboratory. The predominant genera of airborne bacteria identified in the general hospital were *Staphylococcus* spp. (50%), *Micrococcus* spp. (15–20%), *Corynebacterium* spp. (5–20%), and *Bacillus* spp. (5–15%). On the other hand, the predominant genera of airborne fungi identified in the general hospital were *Cladosporium* spp. (30%), *Penicillium* spp. (20–25%), *Aspergillus* spp. (15–20%), and *Alternaria* spp. (10–20%). The detection rate was generally highest on stage 5 (1.1–2.1 μm) for airborne bacteria and on stage 1 (>7.0 μm) for airborne fungi.

Key words: General hospital, Korea, Airborne bacteria, Airborne fungi, Size distribution

Introduction

Social concerns about healthcare-associated infections (HAI), which can be caused by poor hygiene condition such as air contamination and antibiotics abuse in hospital, have been emerged in developed countries since 1900s[1)]. It is the most frequently addressed adverse effect of hospitalization as well as a major public health problem due to morbidity and mortality[2)]. Although many researchers have performed epidemiological investigations to elucidate the source and the transmission mechanism of healthcare-associated infections (HAI) for last thirty years, there is not yet clear conclusion obtained until now[3, 4)].

The principal pathogenic microorganisms known as a potential source to provoke healthcare-associated infections (HAI) by air transmission are *Aspergillus flavus, Gram-negative bacilli, Neisseria meningitidis, Serratia marcescens, Staphylococcus aureus, Streptococcus pyogenes, Streptococcus pneumoniae* and *Tubercle bacilli*[5–9)]. They are derived from skin, hair and clothes of patients and contaminated indoor environment of ward[5)]. Their pathogenicity is transmitted directly from infected persons or by inhalation of infective aerosol generated from the hospital[10)]. The levels of nosocomial pathogens in the air of hospital increase due to dirtiness of air ducts by operation of the Heating, Ventilating and Air Conditioning (HVAC) system without its regular replacement[11)], organic materials such as food, flower and fruit derived from outdoor environment by visitors and contamination of the interior structures by oldness of hospital[12)].

The on-site investigation of general profile of airborne microorganisms distributed in hospital should be preceded prior to suggesting preventive alternatives to restrain the spread infectious disease by nosocomial pathogens. In foreign countries, several studies regarding distribution characteristics of airborne microorganisms in hospital were performed previously[13–15)]. There is, however, relatively little information for airborne microorganisms in general hospitals of Korea although social concerns as regards the healthcare-associated infections (HAI) become

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increasingly widespread. In addition, it is not available to apply foreign data directly to hygienic management guideline of general hospital in Korea because indoor and outdoor environmental conditions, such as climate and topography, of general hospitals located in other countries would be different from those of Korea. Thus, principal objective of the study is to investigate distribution characteristics of airborne bacteria and fungi in the general hospital situated in Korea.

Materials and Methods

Subjects

The study was conducted between March and June in 2007. Five general hospitals located at Seoul of South Korea, which can accommodate 400–600 patient rooms enough to represent large scale of general hospital, were selected. The detailed information related to five general hospitals visited was indicated well in Table 1. Investigation sites in hospital are main lobby, surgical ward, ICU (Intensive Care Unit) and biomedical laboratory.

Each hospital was visited five times, once every two weeks. One sampling in four investigation sites per hospital was done on a visiting day. Therefore, total 25 air samples (5 hospitals × 5 d) were obtained from each investigation site and their average was acknowledged into the representative value for each investigation site. Air sampling was performed at the height of about 1.5 m from the middle of floor of investigation site during daytime (1:00 pm to 5:00 pm). One outdoor site, the air inlet of hospital building, was investigated to compare the measurement data in hospital with those outside hospital.

Measurement

The six-stage viable particulate cascade impactor (Model 10-800, Andersen Inc, USA), adjusted at the flow amount of 28.3 l/min, was utilized for sampling airborne bacteria and fungi. Aerodynamic diameter ranges for each stage in cascade impactor are as followed: stage 1 (>7.0 μm), stage 2 (4.7–7.0 μm), stage 3 (3.3–4.7 μm), stage 4 (2.1–3.3 μm), stage 5 (1.1–2.1 μm), and stage 6 (0.65–1.1 μm). The sum of colony counted between stage 3 and 6 means respirable fraction[16].

The overall procedure of sampling and analysis for airborne bacteria and fungi was based on Kim and Kim's report[17]. Air sampling has been done for 8 to 12 min according to the environmental situation of the measurement locations. Before sampling, the inside of the sampler was disinfected with 70% alcohol and then was inserted with the agar plate according to collection stage. Trypticase soy agar (Lot 2087730, Becton Dickinson and Company, USA), where cycloheximide 500 mg was added to suppress the growth of fungi, was used as bacterial culture medium. For fungal culture, Malt extract agar (Lot 3111376, Becton Dickinson and Company, USA) was used where chloramphenicol 100 mg was applied to suppress the growth of bacteria. The culture media after air sampling were immediately carried to the microbe laboratory and were cultured in the incubator for 1–2 d under a 37°C for bacteria and for 3–5 days under a 20–25°C for fungi, respectively. The concentration of airborne bacteria and fungi, i.e. cfu/m^3, was calculated by dividing by air volume (m^3) the value obtained from counting the colonies formed on the culture medium after the process of culturing.

The genera of all the cultured airborne bacteria were identified according to the classification method of Bergey's manual[18]. After gram's staining of bacteria, additional identification was carried out by conducting biochemical test through the automated microbial identification system, VITEK (Model VITEK 32 system, bioMerieux Inc., France). On the other hand, the airborne fungal genera were identified according to the classification method of Ainsworth and Baron by observing the form, shape and color of colony and spore through the

Table 1. General characteristics of the general hospitals investigated in this study

General hospital	No. of patients	Construction		HVAC system (ACH)
		Age (yr)	Main material	
A	457	8	Concrete & Wood	Central operation (0.8–1.3)
B	513	6	Concrete	Central operation (0.7–1.5)
C	433	9	Concrete & Wood	Central operation (0.7–1.2)
D	588	6	Concrete	Central operation (0.9–1.6)
E	557	7	Concrete	Central operation (0.8–1.4)

optical[19].

Data analysis

SAS package program (SAS/Stat 9.1, SAS Institute Inc., Cary, NC, USA) was applied for the data processing by statistics. The multiple comparative analysis method of ANOVA and Duncan's multiple comparison test was used to assess the concentration differences of airborne bacteria and fungi among the investigation sites.

Results

The level of airborne bacteria and fungi in general hospital of Korea

Table 2 indicates that the profile of airborne bacteria identified in each investigation site of general hospital. Mean total concentration of airborne bacteria was the highest in main lobby ($p<0.05$) followed by surgical ward, biomedical laboratory and ICU. However, there was no significant difference among three investigation sites, surgical ward, biomedical laboratory and ICU ($p>0.05$). Regardless of type of investigation sites, *Staphylococcus* spp. reached to about 50% of totally identified airborne bacteria. The following bacterial genera identified were generally *Micrococcus* spp., *Corynebacterium* spp. and *Bacillus* spp., although a little difference was found among investigation sites. This identification order was similar for both total and respirable concentration. As a result, the above four airborne bacteria were demonstrated to be predominant bacterial genera distributed in the air of general hospitals of Korea because the sum of their identification rates amounted to over 90% of total airborne bacteria measured in them.

In airborne fungi, as indicated in Table 3, main lobby showed the highest level followed by biomedical laboratory, surgical ward and ICU and the significant difference of total concentration was found only in ICU ($p<0.05$). The pattern of respirable concentration, although showing no significant difference among investigation sites in general hospital ($p>0.05$), was also same to that of total concentration. Of total airborne fungi identified in general hospital, the identification rate of *Cladosporium* spp. was the highest, approximately 30%, followed by *Penicillium* spp. (20–25%), *Aspergillus* spp. (15–20%) and *Alternaria* spp. (10–20%). This trend appeared in all the investigation sites and same to respirable fraction. These four fungi covered 85–90% of total airborne fungi identified, demonstrating that they are predominant fungal genera in

Table 2. Identification and level of airborne bacteria in the general hospital

		Main lobby			ICU			Surgical ward			Biomedical laboratory		
		[c]Conc. (cfu/m^3)	(%)	[d]I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio
Staphylococcus spp.	Total	[b]216$^{\alpha}$	58.1	2.9	116$^{\beta}$	57.4	1.5	131$^{\beta}$	44.7	1.7	95$^{\beta}$	43.6	1.3
	[a]Resp.	132$^{\alpha}$	58.4	3.4	81$^{\beta}$	57.0	2.1	93$^{\beta}$	47.2	2.4	53$^{\beta}$	44.5	1.4
Micrococcus spp.	Total	62$^{\alpha}$	16.7	2.1	27$^{\beta}$	13.4	0.9	50$^{\alpha}$	17.1	1.7	46$^{\alpha}$	21.1	1.5
	Resp.	41$^{\alpha}$	18.1	3.2	20$^{\beta}$	14.1	1.5	29$^{\beta}$	14.7	2.2	23$^{\beta}$	19.3	1.8
Corynebacterium spp.	Total	26$^{\alpha}$	7.0	1.2	15$^{\beta}$	7.4	0.7	34$^{\alpha}$	11.6	1.6	50$^{\alpha}$	22.9	2.4
	Resp.	15$^{\alpha}$	6.6	1.0	11$^{\alpha}$	7.7	0.7	23$^{\alpha}$	11.7	1.5	25$^{\alpha}$	21.0	1.7
Bacillus spp.	Total	32$^{\alpha}$	8.6	1.8	18$^{\beta}$	8.9	1.0	44$^{\alpha}$	15.0	2.4	18$^{\beta}$	8.3	1.0
	Resp.	17$^{\alpha}$	7.5	1.4	13$^{\alpha}$	9.2	1.1	26$^{\alpha}$	13.2	2.2	10$^{\alpha}$	8.4	0.8
Enterococcus spp.	Total	5	1.3	-	3	1.5	-	7	2.4	-	3	1.4	-
	Resp.	4	1.8	-	3	2.1	-	6	3.0	-	3	2.5	-
Streptococcus spp.	Total	2	0.5	2.0	3	1.5	3.0	5	1.7	5.0	1	0.5	1.0
	Resp.	2	0.9	2.0	3	2.1	3.0	5	2.5	5.0	1	0.8	1.0
Enterobacteriaceae spp.	Total	3	0.8	-	2	1.0	-	2	0.7	-	1	0.5	-
	Resp.	3	1.3	-	2	1.4	-	2	1.0	-	1	0.8	-
E-Coli spp.	Total	2	0.5	-	2	1.0	-	1	0.3	-	0	0.0	-
	Resp.	2	0.9	-	2	1.4	-	1	0.5	-	0	0.0	-
Klebsiella spp.	Total	0	0.0	-	1	0.5	-	1	0.3	-	0	0.0	-
	Resp.	0	0.0	-	1	0.7	-	1	0.5	-	0	0.0	-
Unidentified	Total	24	6.5	3.0	15	7.4	1.9	18	6.1	2.3	4	1.8	0.5
	Resp.	10	4.4	3.3	6	4.2	2.0	11	5.6	3.7	3	2.5	1.0
Total	Total	372$^{\alpha}$	100.0	2.4	202$^{\beta}$	100.0	1.3	293$^{\beta}$	100.0	1.9	218$^{\beta}$	100.0	1.4
	Resp.	226$^{\alpha}$	100.0	2.7	142$^{\beta}$	100.0	1.7	197$^{\alpha}$	100.0	2.4	119$^{\beta}$	100.0	1.4

[a]Respirable concentration: Sum of airborne bacteria concentration measured on the 3–6 stage. [b]Result of Duncan test: α and β means that averaged values within the row by the same letter are not significantly different (p=0.05). [c]Average value of 25 air samples. [d]Ratio of indoor and outdoor concentration of airborne bacteria.

Table 3. Identification and level of airborne fungi in the general hospital

		Main lobby			ICU			Surgical ward			Biomedical laboratory		
		[c]Conc. (cfu/m^3)	(%)	[d]I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio	Conc. (cfu/m^3)	(%)	I/O ratio
Cladosporium spp.	Total	[b]48^{α}	30.8	4.4	23^{α}	35.4	2.1	28^{α}	29.2	2.5	44^{α}	34.9	4.0
	[a]Resp.	29^{α}	32.6	4.1	16^{β}	34.0	2.3	17^{β}	33.3	2.4	24^{α}	32.4	3.4
Penicillium spp.	Total	37^{α}	23.7	5.3	18^{β}	27.7	2.6	$25^{\alpha\beta}$	26.0	3.6	31^{α}	24.6	4.4
	Resp.	22^{α}	24.7	5.5	11^{β}	23.4	2.8	12^{β}	23.5	3.0	$15^{\alpha\beta}$	20.3	3.8
Aspergillus spp.	Total	27^{α}	17.3	4.5	10^{β}	15.4	1.7	$18^{\alpha\beta}$	18.8	3.0	$18^{\alpha\beta}$	14.3	3.0
	Resp.	16^{α}	18.0	8.0	7^{β}	14.9	3.5	$9^{\alpha\beta}$	17.6	4.5	13^{α}	17.6	6.5
Alternaria spp.	Total	21^{α}	13.5	5.3	8^{β}	12.3	2.0	11^{β}	11.5	2.8	$15^{\alpha\beta}$	11.9	3.8
	Resp.	12^{α}	13.5	12.0	9^{α}	19.1	9.0	6^{α}	11.8	6.0	10^{α}	13.5	10.0
Unidentified	Total	23	14.7	7.7	6	9.2	2.0	14	14.6	4.7	18	14.3	6.0
	Resp.	10	11.2	3.3	4	8.5	1.3	7	13.7	2.3	12	16.2	4.0
Total	Total	156^{α}	100.0	5.0	65^{β}	100.0	2.1	$96^{\alpha\beta}$	100.0	3.1	126^{α}	100.0	4.1
	Resp.	89^{α}	100.0	5.2	47^{α}	100.0	2.8	51^{α}	100.0	3.0	74^{α}	100.0	4.4

[a]Respirable concentration: Sum of airborne fungi concentration measured on the 3–6 stage. [b]Result of Duncan test: α and β means that averaged values within the row by the same letter are not significantly different (p=0.05). [c]Average value of 25 air samples. [d]Ratio of indoor and outdoor concentration of airborne fungi.

the air of general hospitals of Korea.

Size distribution of airborne bacteria and fungi in general hospital

Figures 1 and 2 show the size distribution, by the Andersen cascade air sampler (6 stages), of four predominant airborne bacteria and fungi identified in different areas of general hospital. In predominant airborne bacteria, generally most of them were identified on stage 5 (1.1–2.1 μm) except that the *Bacillus* spp. was detected most frequently on stage 1 (>7.0 μm). On the other hand, the four predominant airborne fungi usually had the highest identification rate on stage 1 (>7.0 μm). The size distribution of indoor predominant airborne microorganisms was different from that of the outdoors. In ICU, the respirable (stage 3 to 6) airborne microorganisms were detected over 50% of the whole although total concentration was even lower compared to other areas of general hospital.

Discussion

Based on the results obtained from this study, the portion of airborne bacteria and fungi having pathogenicity might be considerably low in the general hospitals located in Korea. This finding is in agreement with previous report by Jaffal *et al.*[13] that pathogenic microorganisms showed less than 1% of the total count of bacteria isolated in the air of general hospital. However, they addressed that largest quantities of isolated bacteria were unidentified unlike pattern of predominant bacteria demonstrated from the study. This discrepancy probably seems to occur by difference of identification technique and climate. The diagnostic clinical laboratory technique applied by them was impossible to identify the detail of airborne bacteria because it was devised in terms of only identifying medically important bacteria. Furthermore, the general hospital investigated by them was located in a desert county which is largely different from the study.

According to previous literatures related to identification of airborne fungi in general hospital, the predominant airborne fungal genera were reported to Aspegrillus niger, Chaetomium spp. and *Alternaria* spp. by Jaffal *et al.*[13]; *Aspergillus, Penicillium* and *Fusarium* by Wu *et al.*[20]; and *Penicillium* by Li and Hou[15], therefore, implicating that there is little difference between this result and previous reports.

Similarly to other indoor environments, the fungal genera of *Aspergillus* spp. was detected with high identification rate. This finding could be explained by the fact that several genus of *Aspergillus* spp. have xerophilic property which might enables them to survive in the air for relatively long time[21]. Although the fungal spores of *Aspergillus* spp. were pathogenic microorganisms of small size (2–5 μm)[22], they do not generally have adverse effect on respiratory system of normal people because they are easily removed in the upper respiratory tract. However, special care should be imposed on the *Aspergillus* spp. because it was reported that it easily caused respiratory diseases such as pneumonia, asthma and bronchitis to the immunocompromised like patient if exposed[23].

It is supposed to identify airborne fungi only to the genus. Their hazardousness is different by seed even if they belong to the equal genus. For example, it is assumed that *Aspergills fumigatus* has high hazardousness in the *Aspergillus* spp. Therefore, it is thought whether it is slightly easy-going to consider hazardousness for identification to the genus.

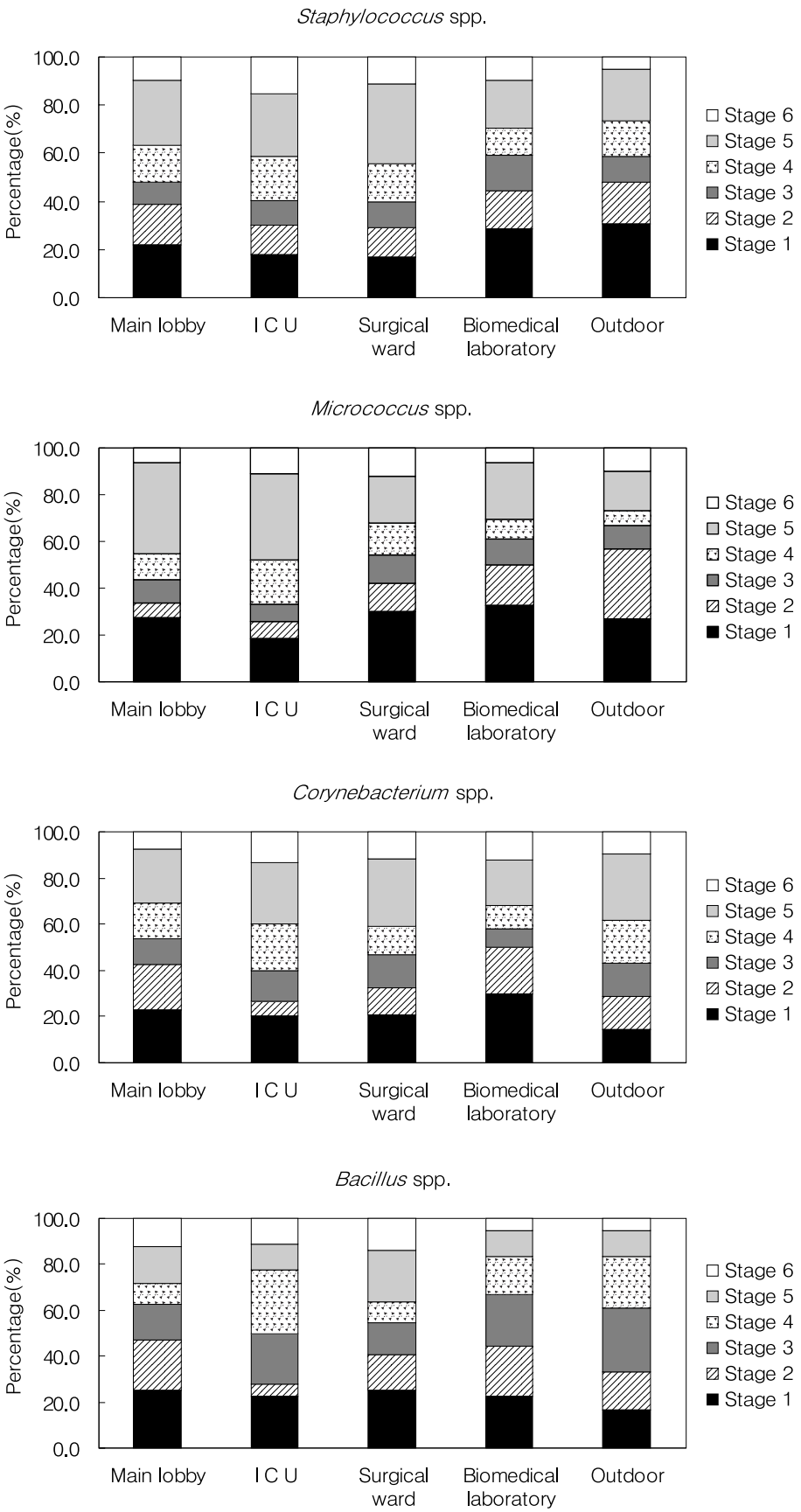

Fig. 1. Size distribution of predominant airborne bacteria in areas of the general hospital.

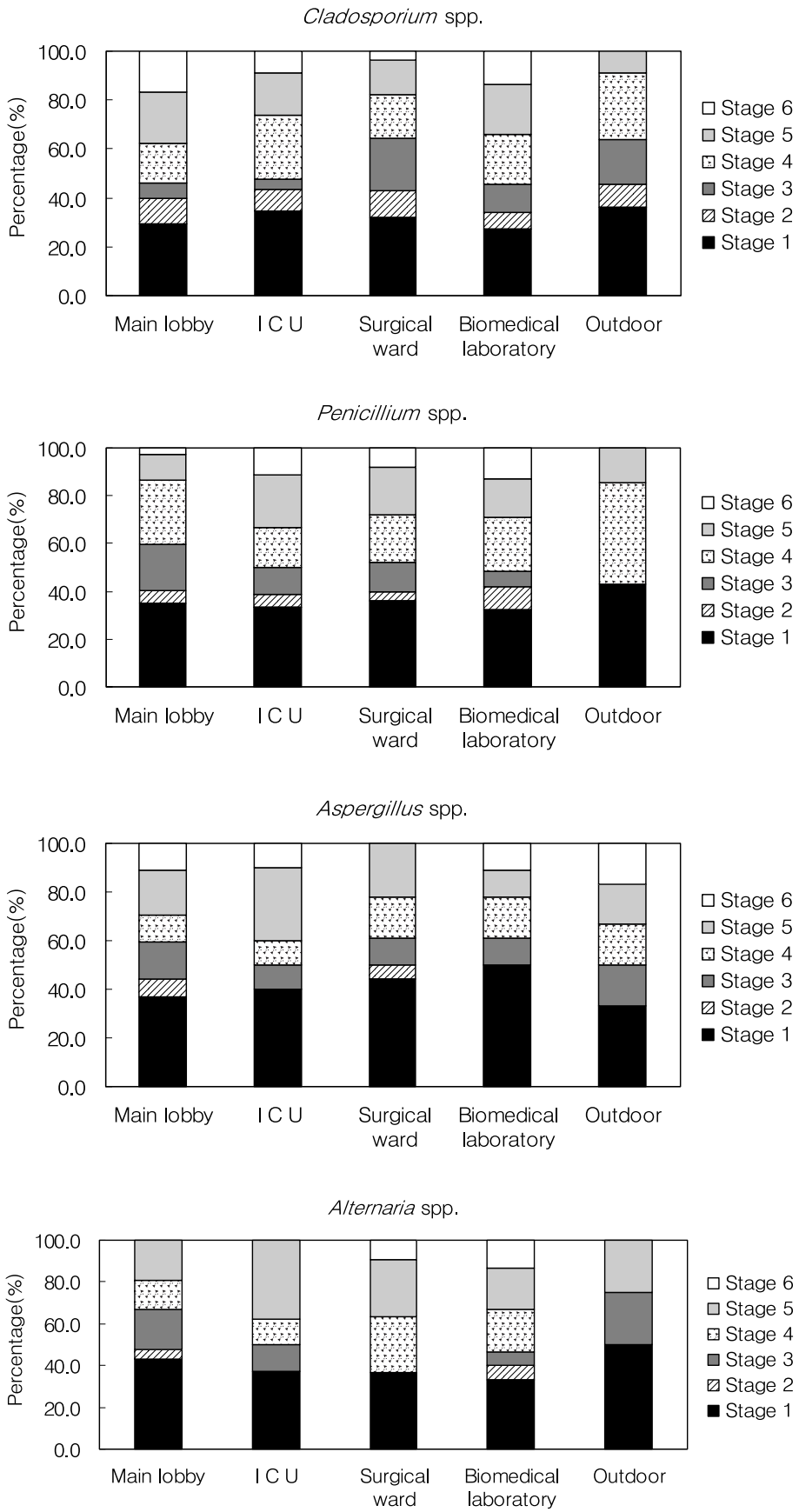

Fig. 2. Size distribution of predominant airborne fungi in areas of the general hospital.

The finding that the level of airborne bacteria was higher than airborne fungi was consistent with the previous study by Li and Hou[15]. Possible explanation for that concentration of airborne bacteria and fungi was the highest in main lobby compared to other different types of hospital area would be frequent comings and goings of many people based on the report by Jaffal *et al*.[13] that bioaerosol level in hospital is determined mainly by human activity. On the other hand, the reason that the ICU had the lowest level of airborne microorganisms might be because it is a clean room applied with high ventilation rate. In addition, source of airborne microorganisms in the ICU would be derived from activity of doctors and nurses because visiting of external people was not allowed severely in case of ICU[24].

Indoor concentration of airborne bacteria and fungi turned out to be higher than the outdoor concentration. Generally, when the ratio of indoor to outdoor concentrations of airborne bacteria and fungi exceeds 1.0, it might be suspected that the indoor air has been contaminated with them[25]. Based on their information, it is assumed that air quality in general hospitals investigated in the study would be degraded by airborne microorganisms. However, the I/O ratio obtained from the study includes a little uncertainty since the inflow of outdoor airborne bacteria and fungi through ventilation contribute to increase of indoor level[26, 27] and the outdoor samples were not taken simultaneously with the indoor samples.

In summary considering previous literatures, the principal factors to affect the level of airborne microorganisms might be not cleanliness of hospital but the activity of people, organic materials derived from the outdoors and ventilation efficiency applied to hospital[13, 15]. Exposure of the immunocompromised people like patients to airborne bacteria and fungi distributed in the air of general hospital can be potentially associated with respiratory diseases[28, 29] although most of airborne microorganisms identified in general hospital do not have pathogenicity.

The finding that size distribution of indoor predominant airborne microorganisms was different from that of the outdoors implies that other indigenous microbial sources would exist in general hospital, which is in contrast with the report by Pastuszka *et al*.[26] and Wu *et al*.[27] that most of indoor airborne microorganisms are derived from the outdoors by ventilation.

The difference of size distribution pattern between bacteria and fungi would be due to differentiation of their shape and size, considering that size of fungal particle is relatively greater than bacterial particle. Additional reasons for the various size distribution of airborne bacteria and fungi might be aerosolization from liquids or reaerosolization along with other particles such as skin flakes, soil particles and respiratory or oral secretions.

Especially airborne bacteria and fungi detected between stage 3 and 6 can result in respiratory diseases to the immunocompromised when inhaled and deposited on the lung. Such a airborne microorganism below 5 μm might be potential hazardous factors to provoke the healthcare-associated infections (HAI) through air transmission[30].

One point to be considered when interpreting the results is a selection of agar media. The media of trypticase soy agar and malt extract agar used in this study for culturing airborne bacteria and fungi have a potential to underestimate their real concentrations in general hospital because it is possible that all the airborne bacteria and fungi distributed in general hospital are not detected in the media. For example, it should be difficult for several species of xerophilic fungi such as *A. penicilloides, A. restriscus, W. sebi*, and *Eurotium* spp. to be cultured in malt extract agar. This fact is a limitation as well as consideration of this study.

Conclusion

In five general hospitals of Korea investigated in this study, the levels of airborne bacteria and fungi were the highest in main lobby as followed by an order of surgical ward, ICU and biomedical laboratory. The predominant genera of airborne bacteria identified in the general hospital were *Staphylococcus* spp. (50%), *Micrococcus* spp. (15–20%), *Corynebacterium* spp. (5–20%), and *Bacillus* spp. (5–15%). On the other hand, the predominant genera of airborne fungi identified in the general hospital were *Cladosporium* spp. (30%), *Penicillium* spp. (20–25%), *Aspergillus* spp. (15–20%), and *Alternaria* spp. (10–20%). The detection rate was generally highest on stage 5 (1.1–2.1 μm) for airborne bacteria and on stage 1 (>7.0 μm) for airborne fungi.

References

1) Leape LL, Brennan TA, Laird N (1991) The nature of adverse events in hospitalized patients: results of the Harvard Medical Practice Study II. N Engl J Med **324**, 377–84.
2) Burke JP (2003) Infection control — a problem for patient safety. N Engl J Med **348**, 651–6.
3) Gaynes RP, Edwards JR, Jarvis WR, Culver DH, Tolson JS, Martone WJ (1996) Noscomial infections among neonates in high-risk nurseries in the United States. Pediatrics **98**, 357–61.
4) Jarvis WR (1996) The epidemiology of colonization. Infect Control Hosp Epidemiol **17**, 47–52.
5) Berthelot P, Graltard F, Amerget C (1999) Investigation of a noscomial outbreak due to *Serratia marcescens* in a materinity hospital. Infect Control Hosp Epidemiol **20**,

233–8.
6) Denning DW (1996) Therapeutic outocme in invasive aspergillosis. Clin Infect Dis **23**, 608–15.
7) Wald A, Leisenring W, Van Burik J, Bowden RA (1997) Epidemiology of aspergillus infections in a large cohort of patients undergoing bone marrow transplantation. J Infect Dis **175**, 1459–66.
8) Manning ML, Archibald LK, Bell LB, Banerjee AN, Jarvis WR (2001) *Serratia marcescens* transmission in a pediatric intensive care unit: a multifactional occurrence. Am J Infect Control **29**, 115–9.
9) Prasad GA, Jones PG, Michaels J, Garland JS, Shivpuri CR (2001) Outbreak of *Serratia marcescens* infection in a neonatal intensive care unit. Infect Control Hosp Epidemiol **5**, 303–5.
10) Haddad SH, Arabi YM, Memish ZA, Al-Shimemeri AA (2004) Nosocomial infective endocarditis in critically ill patients: a report of three cases and review of the literature. Int J Infect Dis **8**, 210–6.
11) Anderson K, Morris G, Kennedy H, Croall J, Michie J, Richardson MD, Gibson B (1996) Aspergillosis in immunocompromised pediatric patients: association with building hygiene, design, and indoor air. Thorax **51**, 256–61.
12) Schabrun S, Chipchase L (2006) Healthcare equipment as a source of nosocomial infection: a systematic review. J Hosp Infect **63**, 239–45.
13) Jaffal AA, Nsanze H, Bener A, Ameen AS, Banat IM, Mogheth AA (1997) Hosptial airborne microbial pollution in a desert country. Environ Int **23**, 167–72.
14) Rolandi L, Lodola L, Guglielminetti M, Caretta G, Azzaretti G (1998) Evaluation of airborne particulate and fungi in critical hospital care units. Toxicol Lett **95** (Suppl 1), 226.
15) Li CS, Hou PA (2003) Bioaerosol characteristics in hospital clean rooms. Sci Total Environ **305**, 169–76.
16) Andersen AA (1958) New sampler for collection, sizing and enumeration of viable airborne particles. J Bacteriol **76**, 471–84.
17) Kim KY, Kim KY (2007) Airborne microbiological characteristics in the public buildings of Korea. Build Environ **42**, 2188–96.
18) Bergey SA (1984) Bergey's mannual of determinative bacteriology, 8th Ed., The Williams & Wilkins, Philadelphia.
19) Ainsworth GC, Baron T (1976) Introduction to the history of mycology. Cambridge University Press, Cambridge.
20) Wu PC, Su HJJ, Ho HM (2000) A comparison of sampling media for environmental viable fungi collected in a hospital environment. Environ Res **82**, 253–57.
21) Guinea J, Peláez T, Alcalá L, Bouza E (2005) Evaluation of Czapeck agar and Sabouraud dextrose agar for the culture of airborne *Aspergillus* conidia. Diagn Microbiol Infect Dis **53**, 333–4.
22) Engelhart S, Hanfland J, Glasmacher A, Krizek L, Schmidt-Wolf IGH, Exner M (2003) Impact of portable air filtration units on exposure of haematology-oncology patients to airborne *Aspergillus fumigatus* spores under field conditions. J Hosp Infect **54**, 300–4.
23) Denning DW (1998) Invasive aspergillosis. Clin Infect Dis **26**, 781–805.
24) Schaal KP (1991) Medical and microbiological problems arising from airborne infection in hospitals. J Hosp Infect **18**, 451–9.
25) Kim KY, Park JB, Jang GY, Kim CN, Lee KJ (2007) Assessment of bioaerosols in the public buildings of Korea. Indoor Built Environ **16**, 465–71.
26) Pastuszka JS, Paw UKT, Lis DO, Wlazlo A, Ulfig K (2000) Bacterial and fungal aerosol in indoor environment in Upper Silesia, Poland. Atmos Environ **34**, 3833–42.
27) Wu PC, Su HJ, Lin CY (2000) Characteristics of indoor and outdoor airborne fungi at suburban and urban homes in two seasons. Sci Total Environ **253**, 111–8.
28) Shin SH, Ponikau JU, Sherris DA, Congdon D, Frigas E, Homburger HA, Swanson MC, Gleich GJ, Kita H (2004) Chronic rhinosinusitis: an enhanced immune response to ubiquitous airborne fungi. J Allergy Clin Immunol **114**, 1369–75.
29) Ruhl LE, Mayfield JL, Woeltje KF (2006) Hospital construction and infection control: does everyone measure up? Am J Infect Control **34**, 104–5.
30) McCluskey R, Sandin R, Greene J (1996) Detection of airborne cytomegalovirus in hospital rooms of immunocompromised patients. J Virol Methods **56**, 115–8.