Characteristics of airborne *Staphylococcus aureus* (including MRSA) in Chinese public buildings

Xiaoxia Li · Yuyu Qiu · Ailian Yu · Weifeng Shi ·
Guomin Chen · Zhong Zhang · Dunjiang Liu

Received: 17 August 2013 / Accepted: 22 April 2014 / Published online: 7 May 2014
© Springer Science+Business Media Dordrecht 2014

Abstract The aim of this study was to evaluate the concentration and size distribution of airborne culturable *Staphylococcus aureus* (*S. aureus*) (including MRSA) in Chinese public buildings. Air samples were collected, using six-stage Andersen sampler from five different public buildings in one large Chinese community. The mean indoor concentrations of the total and respirable airborne *S. aureus* were 72 and 50 CFU/m³ in the general hospital, 72 and 49 CFU/m³ in the kindergarten, 76 and 52 CFU/m³ in the hotel, 84 and 57 CFU/m³ in the movie theater, and 55 and 40 CFU/m³ in the university classroom. Respirable *S. aureus* amounted to approximately 57–73 % of the total *S. aureus* concentrations. Mean total and respirable concentrations of airborne MRSA were 32 and 20 CFU/m³ in the general hospital, 20 and 13 CFU/m³ in the kindergarten, 23 and 16 CFU/m³ in the hotel, 33 and 20 CFU/m³ in the movie theater, and 24 and 17 CFU/m³ in the university classroom. Respirable

MRSA amounted to approximately 61–72 % of the total MRSA concentrations. The ratios of indoor and outdoor concentration for airborne *S. aureus* and MRSA were more than 1.0 in all the investigated public buildings. The size distribution results showed relatively high collection rates on stage 4 (2.1–3.3 µm) for both airborne culturable *S. aureus* and MRSA regardless of the type of public buildings.

Keywords Airborne *Staphylococcus aureus* (*S. aureus*) · Methicillin-resistant *Staphylococcus aureus* (MRSA) · Size distribution · Public buildings

1 Introduction

Airborne and droplet transmission are one of the major routes for spreading human and animal bacteria, such as *Escherichia coli*, *Staphylococcus aureus*, *anthrax*, *Klebsiella pneumonia*, and *Pseudomonas aeruginosa* (Wagenvoort et al. 1993; CDC 2003; Prazmo et al. 2003; Jones et al. 2003). Numerous facts proved that microbial aerosol is a great threat to human and animal health, and a study on the source identification of the origins and transmission of microbial pathogens should be conducted urgently (Li and Hou 2003; Agranovski et al. 2004; Dent et al. 2008; Liu et al. 2012).

Staphylococcus aureus, especially methicillin-resistant *S. aureus* (MRSA), has become one of the

X. Li · Y. Qiu (✉) · A. Yu · W. Shi · Z. Zhang
College of Basic Medicine, Taishan Medical University,
Tai'an 271000, China
e-mail: qyyu1979@163.com

G. Chen
88th Hospital Clinical Laboratory, Chinese People's
Liberation Army, Tai'an 271001, Shandong, China

D. Liu
College of Animal Science and Veterinary Medicine,
Shandong Agricultural University, Tai'an 271018, China

most predominant pathogenic bacteria in hospitals and in the community, which causes diseases of wide concern, e.g., skin and tissue infections, deep abscess formation, pneumonia, endocarditis, osteomyelitis, toxic shock syndrome, and bacteremia endocarditis and bacteremia (Deurenberg et al. 2007; Naseer and Jayaraj 2010; Liu et al. 2012). Although the principal mode of *S. aureus* transmission is contact-spread, the contribution of airborne *S. aureus* to the spread of infection is likely to be greater than is currently recognized, and MRSA is the most frequently isolated airborne microbe (Dürmaz et al. 2005). Shiomori et al. (2001) also indicated that airborne MRSA may play a role in MRSA colonization in the nasal cavity or in respiratory tract infections. Further studies will be needed to assess the levels of *S. aureus*, especially MRSA, contamination of air and to develop more effective means of controlling and removing airborne MRSA in the public buildings. However, compared to other countries, there are little extant data about airborne *S. aureus* or MRSA in China. In this study, the concentration and size distribution of airborne *S. aureus* (including MRSA) in indoor air of different public buildings in China were investigated. These studies could provide information that is available to improve the current ambient air quality standard (AAQS) and is necessary for reducing indoor air contamination by airborne *S. aureus*.

2 Materials and methods

2.1 Public buildings studied

Measurement was taken on sunny days between March and May in 2013 in one large community located at the northern part of Tai'an city of Shandong Province in China. As shown in Table 1, indoor and outdoor air samples were collected and characterized in the following locations: general hospital, kindergarten, hotel, movie theaters, and university teaching building. Two rooms were randomly selected in each public building. All public rooms gave an approval to our phone or written requests for cooperation with this study. Because of the short-term effects of everyday activities on indoor bioaerosol concentrations, there were no residents or human activities in the building during the sampling campaigns.

Table 1 Characteristics of Chinese public buildings investigated in this study

Public buildings	Area	Sampling sites	Ventilation type
General hospital	>300 (ward)	Surgical ward	Mechanical
Kindergarten	>1,000 m ² (area)	Classroom	Natural
Hotel	>100 (room)	Room	Mechanical
Movie theaters	>1,000 m ² (area)	Screens	Mechanical
University teaching building	>50 (room)	Classroom	Natural

2.2 Air sample collection

Air samples were taken from indoor and outdoor air of five public buildings with six-stage Andersen sampler (Andersen 1958) at the flow rate of 28.3 L/min. Aerodynamic diameter ranges for each stage in cascade impactor are as follows: 1 stage (>7.0 µm), 2 stage (4.7–7.0 µm), 3 stage (3.3–4.7 µm), 4 stage (2.1–3.3 µm), 5 stage (1.1–2.1 µm), and 6 stage (0.65–1.1 µm) (Andersen 1958). The Andersen samplers were located near the middle of the room about 1 m above the ground. One outdoor site, the air inlet of each building, was investigated in comparison with the indoor concentration (Kim and Kim 2007). Before sampling, Andersen samplers were equipped with Baird–Parker agar (lot number 060227; Tian He, Hangzhou, China) plates and operated for 8–12 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 the collection stage. The meteorological conditions (temperature, humidity, and wind speed) were monitored in both indoors and outdoors. During the sampling periods, temperatures varied between 21 and 28 °C indoors, and between 14 and 24 °C outdoors, relative humidity indoors varied between 40 and 70 %, and outdoors between 34 and 60 %, wind speed on the days of the monitoring varied between 0.02 and 0.1 m/s indoors, and outdoors between 0.5 and 0.2 m/s.

Two impingers were used at each location per sampling event and represented duplicate samples. Three continuous samplings in each room per building

were collected on each visiting day. Each building was visited three times, once every 2 weeks. In total, 36 indoor samples and 18 outdoor samples were obtained from each public building.

2.3 Isolation, identification, and enumeration of airborne *S. aureus*

The air samples were immediately taken to the microbe laboratory and were processed within 24 h. The Baird–Parker agar plates for air samples were cultured at 37 °C for 24 h. Then, all the colonies generated in the plates were screened for their Gram reaction using the “KOH assay.” All the Gram-positive colonies were subcultured in mannitol salt agar medium, and their species were then identified by using the API 20 E system (BioMerieux, Marcy-l’Etoile, France). The colonies were counted after 24 and 48 h to determine whether the plates were overgrown. The positive-hole correction was applied (Andersen 1958). Concentration of air samples was expressed as colony-forming unit (CFU/m³ air). Finally, *S. aureus* cultures were frozen at –20 °C in LB broth containing 20 % glycerol.

2.4 MRSA isolation and identification

Methicillin resistance was initially confirmed by using acefoxitin disk (30 µg) on Mueller–Hinton agar (CLSI 2011). The *mecA* gene was detected by polymerase chain reaction and primers as previously described (Vannuffel et al. 1998). The forward and reverse primers for *mecA* gene were 5′-AAAATCGATGGT AAA GGTGGC-3′ and 5′-AGTTCTGCAGTACC GGATTTGC-3′. *S. aureus* ATCC 43300 (MRSA) and *S. aureus* ATCC 25923 (MSSA) were used as *mecA*-positive controls and *mecA*-negative controls, respectively. The presence of a 533-bp amplicon was taken as an indication of the presence of the *mecA* gene.

2.5 Data analysis

Statistical Package for the Social Science (SPSS) version 13.0 was applied for the processing of statistics. The multiple comparative analysis method of ANOVA and Duncan’s test was used to assess the differences in the concentrations of airborne *S. aureus* and MRSA among the investigated public buildings.

The significant differences in airborne *S. aureus* and MRSA concentrations between the indoor and outdoor air were analyzed by means of paired *t* test.

3 Results

3.1 Concentrations of airborne *S. aureus* and MRSA in public buildings

As shown in Table 2, the mean concentrations of the total and respirable airborne *S. aureus* were 72 and 50 CFU/m³ in the general hospital, 72 and 49 CFU/m³ in the kindergarten, 76 and 52 CFU/m³ in the hotel, 84 and 57 CFU/m³ in the movie theaters, and 55 and 40 CFU/m³ in the university classrooms, respectively. As a result, both the concentrations of total and respirable airborne *S. aureus* were the highest in movie theaters and it was the lowest in the university classrooms ($p < 0.05$). The mean ratios of respirable *S. aureus* to total airborne *S. aureus* concentrations were 57–73 %, and no significant differences were found among the public buildings ($p > 0.05$). The mean ratios of indoor to outdoor concentrations for total and respirable *S. aureus* were 1.7–2.6 and 1.8–3.0, respectively. The ratios of indoor to outdoor concentrations were the highest in the university classroom ($p < 0.05$). However, the differences between the rest of the public buildings were not statistically significant ($p > 0.05$).

As shown in Fig. 1, the 533-bp desired product was obtained. The concentrations of total and respirable airborne MRSA in public rooms are also shown in Table 2 and were 32 and 20 CFU/m³ in the general hospital, 20 and 13 CFU/m³ in the kindergarten, 23 and 16 CFU/m³ in the hotel, 33 and 20 CFU/m³ in the movie theaters, and 24 and 17 CFU/m³ in the university classrooms, respectively. As a result, both the concentrations of total and respirable airborne MRSA were the highest in movie theaters and it was the lowest in kindergarten ($p < 0.05$). The mean ratios of respirable MRSA to total airborne MRSA concentrations were 61–72 %, and no significant differences were found among the public buildings ($p > 0.05$). The mean ratios of indoor to outdoor concentrations for total and respirable MRSA were 2.0 and 1.9 in the hospitals, 2.0 and 0.9 in the kindergarten, 2.4 and 1.1 in the hotel, and 3.5 and 1.5 in the movie theaters, and 4.8 and 1.7 in the university classrooms, respectively.

Table 2 Concentrations of total and respirable airborne *S. aureus* and MRSA in Chinese public rooms

	General hospital	Kindergarten	Hotel	Movie theaters	University classroom
Airborne <i>S. aureus</i>					
Concentration (CFU/m ³)					
Total					
Max.	102	88	97	119	66
Min.	49	49	53	57	40
Median	68	77	80	84	55
Mean [*]	72 ^{a**}	72 ^c	76 ^{ab}	84 ^b	55 ^d
Respirable ^{***}					
Max.	71	66	66	80	53
Min.	35	31	35	40	27
Median	49	51	55	57	40
Mean	50 ^a	49 ^a	52 ^a	57 ^a	40 ^b
Ratio (%) ^{****}					
Max.	85	75	76	79	40
Min.	58	61	59	61	86
Median	71	70	68	67	62
Mean	71 ^a	68 ^a	69 ^a	57 ^a	73 ^a
I/O ratio ^{*****}					
Total					
Max.	2	2.5	2.9	3.6	3.6
Min.	1.2	1.4	1.6	1.7	1.7
Median	1.7	2.1	2.4	2.5	2.5
Mean	1.7	2.0 ^a	2.3 ^b	2.5 ^a	2.6 ^b
Respirable					
Max.	2.4	3.6	3.5	4.2	4.0
Min.	1.2	1.7	1.9	2.1	2.0
Median	1.8	2.7	2.9	3.0	2.7
Mean	1.8 ^a	2.7 ^a	2.8 ^a	3.0 ^a	2.8 ^b
Airborne MRSA					
Concentration (CFU/m ³)					
Total					
Max.	44	35	44	49	31
Min.	18	9	13	22	13
Median	31	20	22	33	29
Mean	32 ^a	20 ^b	23 ^b	33 ^a	24 ^b
Respirable					
Max.	35	18	27	35	27
Min.	9	4	4	9	9
Median	18	15	13	18	18
Mean	20 ^a	13 ^b	16 ^b	20 ^a	17 ^{ab}
Ratio (%)					
Max.	83	100	100	100	100
Min.	40	33	33	40	50
Median	59	63	73	59	71
Mean	62 ^a	63 ^a	69 ^a	61 ^a	72 ^a

Table 2 continued

	General hospital	Kindergarten	Hotel	Movie theaters	University classroom
I/O ratio					
Total					
Max.	2.6	3.4	4.6	5.1	6.7
Min.	1.1	0.9	1.4	2.3	2.7
Median	2.0	1.9	2.3	3.5	4.7
Mean	2.0 ^a	2.0 ^b	2.4 ^c	3.5 ^c	4.8 ^c
Respirable					
Max.	3.0	1.3	1.9	2.6	3.0
Min.	1.0	0.3	0.3	0.6	0.8
Median	2.0	1.1	0.9	1.3	1.5
Mean	1.9 ^a	1.0 ^c	1.1 ^{bc}	1.5 ^{ab}	1.7 ^a

* Mean concentration of airborne *S. aureus* (A) and airborne MRSA (B) in indoor air ($n = 36$)

** a, b, c means that averaged values within the row followed by the same letter are not significantly different

*** Sum of airborne *S. aureus* concentration measured on the third stage, fourth stage, fifth stage, and sixth stage

**** Value of respirable concentration divided by total concentration

***** Ratios of indoor to outdoor concentrations for total and respirable airborne *S. aureus* and MRSA

Fig. 1 Polymerase chain reaction for *mecA* gene in methicillin-resistant *S. aureus*. M: DL2000 DNA Maker; lane 1: methicillin-resistant *S. aureus* (MRSA) ATCC 43300, lane 2: methicillin-sensitive *S. aureus* (MSSA) ATCC ATCC 25923; lanes 3, 4, 9, 10: airborne strains of methicillin-resistant *S. aureus*; lanes 5, 6, 7, 8: airborne strains of methicillin-susceptible *S. aureus*

The ratios of indoor to outdoor concentrations for total MRSA were the lowest in kindergarten ($p < 0.05$).

3.2 Size distribution of culturable airborne *S. aureus* and MRSA in public buildings

Figures 2 and 3 show the size distribution, determined by the six-stage Andersen sampler, of culturable airborne *S. aureus* and MRSA in different public

buildings. Both the distribution ratios of indoor and outdoor airborne *S. aureus* were highest for a particle diameter of 2.1–3.3 μm (4th stage) in the general hospital, hotel, and movie theaters and show the highest collection rate at stage 3 (3.3–4.7 μm) in the university classrooms. The distribution ratio was generally highest on stage 2 (4.7–7.0 μm) for airborne *S. aureus* in indoor air of kindergarten (Figs. 2a, 3a).

The size distribution of airborne MRSA showed relatively high collection rates at third stage in indoor air of the hotel, movie theaters rooms, and university classrooms, at second stage in indoor air of the general hospital and the kindergarten (Figs. 2b, 3b). It showed equally high collection rates at the second and fourth stages in outdoor air of general hospital and kindergarten, respectively (Figs. 2b, 3b).

Regardless of the kind of the public buildings, isolates of airborne *S. aureus* and MRSA were detected in all stages [from stage 1 ($>7 \mu\text{m}$) to stage 6 (0.65–1.1 μm)], and the size distribution in indoor air is showing the highest collection rate at stage 4 (2.1–3.3 μm).

4 Discussion

Although emergence of respiratory viral pathogens such as SARS, avian influenza viruses, and 2009 H1N1

Fig. 2 Mean concentration of airborne *S. aureus* **a** and airborne MRSA **b** on each stage of six-stage Andersen sampler in Chinese public buildings (each data point represents mean $\pm$ SD, $n = 36$)

influenza virus had attracted widespread public attention in China, systematic investigations of airborne pathogenic microorganisms in public buildings have not been performed. Airborne *S. aureus* (including MRSA), known as the commonly isolated airborne microbe (Dürmaz et al. 2005), is investigated in the present study. Our field results demonstrate that both the concentrations of total and respirable airborne *S. aureus* were the highest in movie theaters and it was the lowest in the university classrooms (Table 2). Previous study showed that the range of mean total concentration of *Staphylococcus* spp. was 16–58 CFU/m³ in Korea public buildings (Kim and Kim 2007). Gandara et al. (2006) reported that the average recovered concentration of the respirable *S. aureus* in Texas

homes was only 15 CFU/m³. The *Staphylococcus* spp. counts ranged from 55 to 84 CFU/m³ in the present study. Based on these results, the concentration of airborne *S. aureus* showed inconsistency among different countries. Therefore, it may not be appropriate to apply foreign data directly to hygienic management guideline of public buildings in China. Therefore, the present study is very necessary. The ratio of respirable to total airborne *S. aureus* inside the building ranged from 57–73 % in the present study, which was higher than the foreign reports that showed a range of 30–60 % (DeKoster and Thorne 1995; Pastuszka et al. 2000; Kim and Kim 2007; Kim et al. 2010).

Since the methicillin-resistant *S. aureus* (MRSA) was discovered in 1961, it has become one of the most

Fig. 3 Size distribution of airborne *S. aureus* **a** and airborne MRSA **b** according to the six-stage Andersen sampler in Chinese public buildings [aerodynamic diameter ranges: 1 stage

(>7.0 μm), 2 stage (4.7–7.0 μm), 3 stage (3.3–4.7 μm), 4 stage (2.1–3.3 μm), 5 stage (1.1–2.1 μm), and 6 stage (0.65–1.1 μm)]

predominant pathogenic bacteria in nosocomial and community-acquired infections and extensive research of MRSA had emerged worldwide (Jevons 1996; Hsueh et al. 2004; Cimolai 2010; Deleo et al. 2010; Otter and French 2010). The studies of *S. aureus* (including MRSA) strains isolated from clinical specimens, such as sputum, urine, pus or secretions, and blood, have already been reported frequently in China and abroad. Airborne MRSA may play a role in respiratory tract MRSA infections, and measures should be taken to prevent the spread of airborne MRSA (Shiomori et al. 2001). Therefore, the concentration of airborne MRSA was also evaluated in this study. The results showed that mean total concentrations of airborne MRSA were 20–33 CFU/m³ in the

investigated buildings (Table 2). Considering the previous reports, the mean total of airborne MRSA was 59–73 CFU/m³ in bedsheets in surgery unit (Shiomori et al. 2001).

Over the last decade, community-acquired MRSA (CA-MRSA) causing primarily skin and soft tissue infections has emerged as a major cause of disease in the general population in day cares, schools, prisons, and sport teams around the world (King et al. 2006; Roberts et al. 2011, 2013). MRSA has been isolated from recreational beaches, high-touch surfaces in homes, universities, and other community environmental surfaces (Roberts et al. 2013). However, there have been few recent studies demonstrating the detection and isolation of airborne MRSA in different

public buildings. The results of the present study demonstrated that airborne MRSA was present in all buildings studied, which is clearly worth considering.

The ratios of indoor to outdoor concentrations of airborne *S. aureus* and MRSA in all the investigated public buildings exceeded 1.0 (Table 2), which demonstrated that the indoor air has been contaminated with airborne *S. aureus* and MRSA (Li and Kuo 1993; Kim and Kim 2007; Kim et al. 2010).

The size of airborne bacteria determines the location in the respiratory system where the inhaled airborne bacteria are deposited (Kim and Kim 2007). In humans, aerosol particles $\leq 5 \mu\text{m}$ are capable of reaching deep into the respiratory tract and being deposited in alveolar tissues. Aerosols of this size, as well as larger particles, can be deposited via inertial impaction in the upper airway, where airflow velocity is greatest, at points in the respiratory tract of airflow directional (Kortney et al. 2011). Regardless of the kind of the public buildings, the size distribution of airborne *S. aureus* (including MRSA) in indoor air is showing the highest collection rate at stage 4 and stage 3, respectively (Figs. 2, 3). The results showed that most of airborne *S. aureus* in indoor air could deposit in the lower regions of the human respiratory tract. However, the previous study indicated that *Staphylococcus spp.* showed relatively high collection rates at first ($>7.0 \mu\text{m}$) and second ($4.7\text{--}7.0 \mu\text{m}$) stages (Kim and Kim 2007). The size distribution of airborne *S. aureus* showed inconsistency in the public buildings (Figs. 2, 3), which appears to be due to the indoor environmental condition like everyday indoor activities or the discharge mechanism related to the velocity of air flow near the microbial habitat in the indoor structures (Li and Hou 2003; Kim and Kim 2007). Further research is needed to determine the cause of inconsistency. The distribution of outdoor airborne *S. aureus* was considerably similar to the indoor distribution and was consistent with the previous results (Di Giorgio et al. 1996; Kim and Kim 2007).

Once airborne microorganisms are exposed to a variety of environmental stresses, the most important ones are being the effects of temperature, relative humidity (RH), and wind speed (Li and Hou 2003; Kim and Kim 2007). To minimize the impact of meteorological variations, sampling was generally conducted under certain temperature, relative humidity (RH), and wind speed conditions in our study.

The limitation of this field study is that it was conducted only in the 3-month period in the spring, and it would not completely reflect the weather conditions of our country that has four distinct seasons. Moreover, the number of public buildings investigated in the present study was a relatively small size. Therefore, further larger studies should be performed intensively. Emphasis should be placed on routine air sampling in public buildings, which would provide a clearer picture of the relationship between airborne microbes and infection rates.

Acknowledgments This study was sponsored by the following foundation programs: a Grant (No. 81101307) from the National Science Council, Republic of China; Taishan Medical University research project (No. 2010ZR035) and research project for doctor (No. 2010); Taishan Medical University high-grade research project (No. 2012GCC15); and college students' innovative entrepreneurial training project (No. 201310439012).

References

- Agranovski, I. E., Safatov, A. S., Pyankov, O. V., Sergeev, A. N., Agafonov, A. P., Ignatiev, G. M., et al. (2004). Monitoring of viable airborne SARS virus in ambient air. *Atmospheric Environment*, 38, 3879–3884.
- Andersen, A. A. (1958). New sampler for the collecting, sizing and enumerating of viable airborne particles. *Journal of Bacteriology*, 76, 471–484.
- Centers for Disease Control and Prevention (CDC). (2003). Follow-up of deaths among U.S. Postal Service workers potentially exposed to *Bacillus anthracis*- District of Columbia, 2001–2002. *Morbidity and Mortality Weekly Report*, 52, 937–938.
- Cimolai, N. (2010). Methicillin-resistant *Staphylococcus aureus* in Canada: a historical perspective and lessons learned. *Canadian Journal of Microbiology*, 56, 89–120.
- CLSI. (2011). *Performance standards for antimicrobial susceptibility testing; 16th informational supplement*. Wayne, PA: Clinical and Laboratory Standards Institute.
- DeKoster, J. A., & Thorne, P. S. (1995). Bioaerosol concentrations in noncomplaint, complaint and intervention homes in the Midwest. *American Industrial Hygiene Association Journal*, 56, 576–580.
- Deleo, F. R., Otto, M., Kreiswirth, B. N., & Chambers, H. F. (2010). Community-associated methicillin-resistant *Staphylococcus aureus*. *The Lancet*, 375, 1557–1568.
- Dent, J. E., Kao, R. R., Kiss, I. Z., Hyder, K., & Arnold, M. (2008). Contact structures in the poultry industry in Great Britain: exploring transmission routes for a potential avian influenza virus epidemic. *BMC Veterinary Research*, 4, 27.
- Deurenberg, R. H., Vink, C., & Kalenic, S. (2007). The molecular evolution of methicillin-resistant *Staphylococcus aureus*. *Clinical Microbiology and Infection*, 13, 222–235.

- Di Giorgio, C., Krempff, A., Guiraud, H., Binder, P., Tiret, C., & Dumenil, G. (1996). Atmospheric pollution by airborne microorganisms in the city of Marseilles. *Atmospheric Environment*, 30, 155–160.
- Dürmaz, G., Kiremitçi, A., Akgün, Y., Oz, Y., Kaşifoğlu, N., Aybey, A., et al. (2005). The relationship between airborne colonization and nosocomial infections in the intensive care unit. *Mikrobiyoloji Bulteni*, 39, 465–471.
- Gandara, A., Mota, L. C., Flores, C., Perez, H. R., Green, C. F., & Gibbs, S. G. (2006). Isolation of *Staphylococcus aureus* and antibiotic-resistant *Staphylococcus aureus* from residential indoor bioaerosols. *Environmental Health Perspectives*, 114, 1859–1864.
- Hsueh, P. R., Teng, L. J., Chen, W. H., Pan, H. J., Chen, M. L., Chang, S. C., et al. (2004). Increasing prevalence of methicillin-resistant *Staphylococcus aureus* causing nosocomial infections at a university hospital in Taiwan from 1986 to 2001. *Antimicrobial Agents and Chemotherapy*, 48, 1361–1364.
- Jevons, M. P. (1996). “Cellbenin”-resistant *staphylococci*. *British Medical Journal*, 1, 124–125.
- Jones, A., Govan, J., Doherty, C., Dodd, M., Isalska, B., Stanbridge, T., et al. (2003). Identification of airborne dissemination of epidemic multiresistant strains of *Pseudomonas aeruginosa* at a CF centre during a cross infection outbreak. *Thorax*, 58, 525–527.
- Kim, K. Y., & Kim, C. N. (2007). Airborne microbiological characteristics in public buildings of Korea. *Building and Environment*, 42, 2188–2196.
- Kim, K. Y., Kim, Y. S., & Kim, D. (2010). Distribution characteristics of airborne bacteria and fungi in the general hospitals of Korea. *Industrial Health*, 48, 236–243.
- King, M. D., Humphrey, B. J., Wang, Y. F., Kourbatova, E. V., Ray, S. M., & Blumberg, H. M. (2006). Emergence of community-acquired methicillin-resistant *Staphylococcus aureus* USA 300 clone as the predominant cause of skin and soft-tissue infections. *Annals of Internal Medicine*, 144, 309–317.
- Kortney, M. G., Jessica, A. B., Debra, A. W., Melissa, B. P., Jacqueline, M. K., Terrence, M. T., et al. (2011). Maines1 Influenza virus aerosol exposure and analytical system for ferrets. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 8432–8437.
- Li, C. S., & Hou, P. A. (2003). Bioaerosol characteristics in hospital clean rooms. *Science of the Total Environment*, 305, 169–176.
- Li, C. S., & Kuo, Y. M. (1993). Microbiological indoor air quality in subtropical areas. *Environment International*, 19, 233–239.
- Liu, D. J., Chai, T. G., Xia, X. Z., Gao, Y. W., Cai, Y. M., Li, X. X., et al. (2012). Formation and transmission of *Staphylococcus aureus* (including MRSA) aerosols carrying antibiotic-resistant genes in a poultry farming environment. *Science of the Total Environment*, 426, 139–145.
- Naseer, B. S., & Jayaraj, Y. M. (2010). Identification of multi-resistant *Staphylococcus aureus* in clinical specimens. *Research Journal of Medical Sciences*, 4, 204–207.
- Otter, J. A., & French, G. L. (2010). Molecular epidemiology of community-associated methicillin-resistant *Staphylococcus aureus* in Europe. *Lancet Infectious Diseases*, 10, 227–239.
- Pastuszka, J. S., Paw, U. K. T., Lis, D. O., Wlazlo, A., & Ulfig, K. (2000). Bacterial and fungal aerosol in indoor environment in Upper Silesia, Poland. *Atmospheric Environment*, 34, 3833–3842.
- Prazmo, Z., Dutkiewicz, J., Skłarska, C., Sitkowska, J., & Cholewa, G. (2003). Exposure to airborne gram-negative bacteria, dust, and endotoxin in paper factories. *Annals of Agricultural and Environmental Medicine*, 10, 93–100.
- Roberts, M. C., Soge, O. O., Horst, J. A., Ly, K. A., & Milgrom, P. (2011). MRSA from dental school surfaces and students. *American Journal of Infection Control*, 39, 628–632. doi:10.1016/j.ajic.2010.09.008.
- Roberts, M. C., Soge, O. O., & No, D. (2013). Comparison of multi-drug resistant environmental methicillin-resistant *staphylococcus aureus* isolated from recreational beaches and high touch surfaces in built environments. *Frontiers Microbiology*, 4(4), 74. doi:10.3389/fmicb.2013.00074.
- Shiomori, T., Miyamoto, H., & Makishima, K. (2001). Significance of airborne transmission of methicillin-resistant *Staphylococcus aureus* in an otolaryngology-head and neck surgery unit. *Archives of Otolaryngology-Head and Neck Surgery*, 127, 644–648.
- Vannuffel, P., Laterre, P., Bouyer, M., Gigi, J., Vandercam, B., Reynaert, M., et al. (1998). Rapid and specific molecular identification of methicillin-resistant *Staphylococcus aureus* in endotracheal aspirates from mechanically ventilated patients. *Journal of Clinical Microbiology*, 36, 2366–2368.
- Wagenvoort, J. H. T., Davies, B. I., Westerman, E. J. A., Werink, T. J., & Toenbreker, H. M. J. (1993). MRSA from air-exhaust channels. *The Lancet*, 341, 840–841.