

Research Article

Analysis of Air Purification Methods in Operating Rooms of Chinese Hospitals

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This research demonstrates the current use of air purification methods in the operating rooms (ORs) in China. 154 hospitals from 6 provinces were included in this survey to reflect the air purification methods of ORs in 2017. Air cleaning technology (ACT) is used in 124 (80.52%) hospitals. We find that the rates of using grade I, III, or IV clean operating room (COR) in tertiary hospitals are all higher than in lower level hospitals; the rate of using ACT in the ORs is higher, too. In addition, general hospitals have higher rate in using ACT in the ORs than specialized hospitals. The highest rate of using ACT in the ORs is in the eastern region of China. The number of hospitals using ACT, ultraviolet light disinfection, and air sterilizers (such as circulating air UV sterilizer) increased yearly. All grades of CORs can be maintained as required by more than 90% hospitals except grade II COR. In this research, we found air purification methods, especially the ACT, are widely used in hospitals' ORs. However, finding the way to select and use different air purification methods correctly is an urgent problem to be solved next.

1. Introduction

Health care-associated infection (HAI) affects the quality of medical care and the safety of health care workers and patients. It also brings a financial burden to the patients and hospitals [1–4]. Surgical-site infection (SSI) is one of the most common HAIs with high morbidity and mortality [5–7]. A study of SSI involving four kinds of surgeries (colorectal surgery, abdominal hysterectomy, femoral neck repair surgery, and vascular surgery) in 29 hospitals in China represented a SSI rate of 1.6% in 2014 [8]; this rate was higher than 0.9% in the US (reported by the National Healthcare Safety Network (NHSN), 2014) [3]. A recent study in the Netherlands also showed that the increased cost of SSI is reaching to €21,569 per case and

total costs of DALYs for the three surgery types (colectomy, mastectomy, and total hip arthroplasty) exceeded to €88 million [9].

Researchers report that air microbial contamination in the OR is one of the risk factors for SSI [5, 10]. In 2016, the World Health Organization (WHO) released “Global Guidelines for the Prevention of Surgical Site Infection.” They pointed out the importance of improving the air quality of the OR to prevent SSIs [11]. By properly and rationally using air purification methods, the air quality of ORs can be improved and contribute to reduce the risk of SSI to a certain extent [12, 13]. In 1972, a study on airborne contamination and the deep infection rate published by Charnley showed that, when the ventilation and microbiological performance of the OR were improved, the infection

rate would reduce from 7% to 0.5% [14]. Many studies suggested that laminar air flow (LAF) systems and ultraviolet air disinfection in ORs can significantly reduce the SSI rate [15, 16].

In order to regulate the air purification methods in hospitals in China, the Chinese government promulgated the standard “Management Specification of Air Cleaning Technique” in 2012. This standard is aimed for regulating the air purification methods in ORs and usage requirements [17]. The standard has been implemented for more than six years. During this time, many hospitals have undergone significant changes in air purification methods in ORs and new air purification methods have emerged. However, during this period, most of the studies are focusing on the effect of reducing SSIs, only a few of them focused on the status of air purification methods in ORs. Learning the types and composition of air purification methods used in ORs is necessary for the management and the development of air purification methods. In order to understand the current status of air purification methods in China and provide a basis for the management of air purification methods, we conducted this investigation nationwide.

2. Materials and Methods

2.1. Sampling Methods. A stratified sampling was conducted in six provinces from three regions of China (East, Central, and West). Provincial capital and two prefectural or municipal level cities were selected in each province. We selected 8~9 hospitals from each city for investigation, including at least one prefectural or municipal level general hospital, one district or county level general hospital, and one specialized hospital. Besides, 1 provincial or ministerial level general hospital was investigated in each province.

2.2. Data Collection and Management. The questionnaire was revised and improved by reviewing of the literature and consulting the experts, and then the unified design questionnaire was sent to the surveyed hospitals via a professional questionnaire network. We collected the basic information of hospitals including the hospital level, hospital type, number of beds, annual surgery volume, and air purification methods of ORs in 2017, distribution of various air purification methods in different years, and maintenance of air purification methods. After the reporting of data, the trained staff reviewed the data for errors and inconsistencies and verified data by telephone return visit. In addition, we verified the data reported by hospitals of two provinces in the field investigation. Unverifiable data were processed by “unknown.”

2.3. Definitions

2.3.1. Air Cleaning Technology (ACT). Air cleaning technology is a technique that reduces airborne contaminants concentration by delivering air through a high-efficiency air

filter and can be divided into turbulent flow and laminar flow according to the air distribution [13, 18].

2.3.2. Clean Operating Room (COR). It is the operating room where the total amount of microorganisms and dust particles in the operating environment air are reduced to an allowable level by using ACT. The classification of clean operating room is shown in Table 1 [19].

2.3.3. Chinese Hospital Level. The evaluation system of medical institutions implemented in China divided medical institutions into three levels (tertiary, secondary, and first) through comprehensive evaluation of service quality, technical level, and management level [20]. Some hospitals have not participated in the evaluation yet.

2.4. Data Analysis. Categorical variables are expressed as absolute numbers and their relative frequencies. The χ^2 test and Bonferroni method were used to test the differences on rates of using different air purification methods among hospital types, hospital levels, and regions. All statistical analyses were two-sided, and $p < 0.05$ was considered significant. Also, SPSS, version 22.0 was used for data analysis.

3. Results

A total of 154 hospitals were investigated, including 12 (7.79%) provincial or ministerial level hospitals, 82 (53.25%) prefectural or municipal level hospitals, and 60 (38.96%) county level hospitals. The characteristics of investigated hospitals, such as hospital level, hospitals type, region, no. of beds, and annual surgery volume, are shown in Table 2.

Among the 154 hospitals, ACT was the most common air purification method in the OR (124 hospitals (80.52%)). Among the 124 hospitals using ACT in the OR, 46 (37.10%) hospitals built only one grade of COR, and 78 (62.90%) built more than one grade of COR (Tables 3 and 4).

The rate of using ACT in the OR of tertiary hospitals was higher than that of lower level hospitals ($p < 0.05$), and we found the rates of using grade I COR, grade III COR, and grade IV COR were higher in tertiary hospitals ($p < 0.05$). The rate of using ACT in the OR in general hospitals was higher than the rate in specialized hospitals ($p < 0.05$), and the difference is mainly caused by the different rate of the grade I COR. Compared with the central and western regions in China, respectively, there were higher rates of using ACT in the OR in the eastern region ($p < 0.05$), and further analysis for different grade of CORs found that the rate of grade I COR was higher in the eastern region than that in other regions ($p < 0.05$) (Tables 5 and 6).

From 2001 to 2017, the number of hospitals using ACT, ultraviolet light disinfection, circulating air UV air sterilizer, electrostatic adsorption air sterilizer, and central air conditioning system with air purification device in ORs gradually increased year by year. Among these air purification methods, the number of hospitals using ACT in ORs always occupied top place every year from 2000 to 2017 and

TABLE 1: Classification of clean operating room.

Grade	Airborne bacterial concentration (at rest)	
	Operating zone (cfu/m ³)	Surrounding zone (cfu/m ³)
I	5	10
II	25	50
III	75	150
IV	175	

TABLE 2: Characteristics of surveyed hospitals.

Characteristics	No. of hospitals	Proportion (%)
Hospital level		
Tertiary	91	59.09
Secondary and lower	63	40.91
Hospital type		
General	117	75.97
Specialized	37	24.03
Region		
East	53	34.41
Central	50	32.47
West	51	33.12
No. of beds		
<400 beds	38	24.67
400~899 beds	51	33.12
>900 beds	65	42.21
Annual surgery volume		
<2000	39	25.32
2000~	47	30.52
6000~	68	44.16
Total	154	100.00

increased from 4 (2.60%) in 2000 to 118 (76.62%) in 2017 (Figure 1).

In more than 90% hospitals, grade I CORs, grade III CORs, and grade IV CORs can meet the requirement, while three of the four hospitals can maintain grade II CORs as required. All of the surveyed hospitals can maintain circulating wind UV sterilizer, ultraviolet light disinfection, electrostatic adsorption air sterilizer, and central air conditioning ventilation system with air purification device and mechanical ventilation as required. (Table 7).

4. Discussion

Since the first promulgation of the Architectural Technical Code for Hospital Clean Operating Department (GB50333) [19] in 2002, the number of hospitals with CORs has increased significantly in China. Provincial or municipal hospitals and even county level hospitals have begun to establish large-scale, high-standard CORs [21, 22]. This survey found, as of 2017, more than 80% of the hospitals have adopted ACT. Among them, more than 50% of hospitals have built the grade I COR and grade III COR, and most of hospitals with CORs are concentrated in economically developed eastern region. It can be seen that the ACT has become the most widely used air purification method in ORs in China nowadays. And, the number of hospitals using ACT in ORs has increased rapidly year by

year, especially the grade I COR and the grade III COR. Standard drafter Jinming Shen once said that the misinterpretation for the norms is one of the reasons for accelerating the construction of CORs. He stressed that the purpose of formulating Architectural Technical Code for Hospital Clean Operating Department was to regulate the construction of the COR rather than to cancel the general OR [23]. In this survey, only four hospitals used the grade II COR, which were much less than the number of hospitals with other grades CORs. Owing to the standard Architectural Technical Code for Hospital Clean Operating Department (GB50333) [15], the requirements for the main technical indicators, basic equipment, layout, indoor decoration, air cleaning and conditioning system, etc. of the grade I COR and those of the grade II COR are almost identical; therefore, many hospitals preferred to build grade I CORs with higher cleanliness level.

ACTs have been widely used in ORs of China, but the effect of ACT on preventing SSIs, especially the LAF, has been controversial [11, 24–26]. In 2016, the WHO released the “Global Guidelines for The Prevention of Surgical Site Infection” [11], the guidelines recommend that “the panel suggests that laminar airflow ventilation systems should not be used to reduce the risk of SSI for patients undergoing total arthroplasty surgery,” but it also mentioned that because the data used in the study were not specifically designed for LAF effects on SSIs, it may be affected by factors such as the number of hospitals, surgeons, characteristics, or implementation of patients admitted. And, the guidelines also mentioned that the single studies found that LAF has different effects on the risk of SSI for different types of surgeries.

In addition, there are also differences in the recommended cleanliness level of the OR for different types of surgeries among countries. In the United States, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 170-2017 “Ventilation of Health Care Facilities” [27] mentioned that high-risk special operating room is recommended for large-scale surgery requiring general or large-area local anesthesia and vital function maintenance equipment, which is equivalent to grade I COR in China. The standard Architectural Technical Code for Hospital Clean Operating Department (GB50333) [15] in China recommended grade I COR for prosthesis, implantation, some large organ transplants, and surgery with SSI which will directly endanger life and quality of life.

At last, the construction costs on CORs and the maintenance costs of LAF are extremely high. A study in Italy concluded that construction costs of CORs have increased by 24% and annual operating costs have increased by 36% [28]. Domestic research indicated the annual operating cost of a grade I COR can reach more than 100,000 yuan [21, 29, 30]. The construction and maintenance of CORs can increase the national medical expenditure, and the unqualified construction and inadequate maintenance of CORs will make the air cleaning equipment a source of airborne microbial contamination [31, 32], and the low-price bidding policy in China further affected the construction quality of

TABLE 3: Air purification methods in operating rooms of surveyed hospitals.

Air purification methods	No. of hospitals	Proportion (%)
ACT	124	80.52
Circulating wind UV sterilizer	7	4.54
Electrostatic adsorption air sterilizer	6	3.90
Central air conditioning system with air purification device	6	3.90
Ultraviolet light disinfection	6	3.90
Ultraviolet light disinfection and air sterilizer*	3	1.94
Mechanical ventilation	2	1.30
Total	154	100.00

*Air sterilizer included electrostatic adsorption air sterilizer, circulating wind UV sterilizer, and plasma air sterilizer.

TABLE 4: Different grade clean operating rooms of surveyed hospitals.

Different grades of COR	No. of hospitals	Proportion (%)
I and III	50	40.32
III	24	19.35
I	19	15.32
I, III, and IV	17	13.71
III and IV	7	5.65
IV	3	2.42
I, II, and III	2	1.61
II and III	1	0.81
I, II, III, and IV	1	0.81
Total	124	100.00

TABLE 5: Analysis of air clean technology in operating rooms of surveyed hospitals.

Characteristics	Total no. of hospitals	No. of hospitals using ACT in ORs (%)	χ^2	<i>p</i> value
Hospital level			13.04	<0.01
Tertiary	91	82 (90.11)		
Secondary and lower	63	42 (66.67)		
Hospital type			7.61	0.01
General	117	100 (85.47)		
Specialized	37	24 (64.86)		
Region			7.34	0.03
East	53	49 (92.45)		
Central	50	37 (74.00)		
West	51	38 (74.51)		

TABLE 6: Analysis of different grade clean operating room in surveyed hospitals.

Characteristics	No. of hospitals	No. of hospitals using the COR I (%)	χ^2	<i>p</i> value	No. of hospitals using the COR III (%)	χ^2	<i>p</i> value	No. of hospitals using the COR IV (%)	χ^2	<i>p</i> value
Hospital level			9.75	<0.01		11.37	<0.01		4.76	0.03
Tertiary	91	62 (68.13)			70 (76.92)			23 (25.27)		
Secondary and lower	63	27 (42.86)			32 (50.79)			7 (11.11)		
Hospital type			23.36	<0.01		0.36	0.55		1.11	0.29
General	117	80 (68.38)			79 (67.52)			25 (21.37)		
Specialized	37	9 (24.32)			23 (62.16)			5 (13.51)		
Region			6.42	<0.05		0.47	0.79		1.36	0.51
East	53	38 (71.70)			37 (69.81)			13 (24.53)		
Central	50	25 (50.00)			32 (64.00)			8 (16.00)		
West	51	26 (50.98)			33 (64.71)			9 (17.65)		

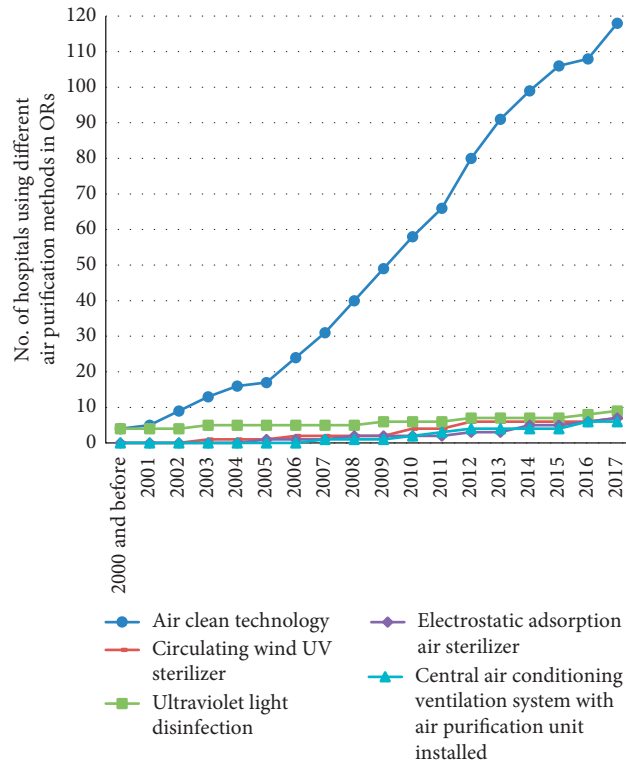


FIGURE 1: Distribution of various air purification methods in different years. The data are missing for 6 hospitals using ACT in ORs and missing for 1 hospital using circulating wind UV sterilizer in ORs.

TABLE 7: Analysis of the maintenance of different air purification methods in surveyed hospitals' ORs.

Air purification methods	No. of hospitals	No. of hospitals with clean maintenance (%)	No. of hospitals replacing key components as required (%)
Grade I of ACT	89	86 (96.63)	85 (95.51)
Grade II of ACT	4	3 (75.00)	3 (75.00)
Grade III of ACT	102	97 (95.10)	99 (97.06)
Grade IV of ACT	30	29 (96.67)	29 (96.67)
Ultraviolet light disinfection	9	9 (100.00)	9 (100.00)
Circulating wind UV sterilizer	8	8 (100.00)	8 (100.00)
Electrostatic adsorption air sterilizer	7	7 (100.00)	7 (100.00)
Central air conditioning ventilation system with air purification device	6	6 (100.00)	6 (100.00)
Mechanical ventilation	2	2 (100.00)	2 (100.00)

CORs and maintenance [33]. Faced with these questions, should the hospital continue to build CORs and how to properly use ACT in ORs? Hu [33] believed that hospitals should establish CORs according to their own scale, mission requirements, nature, etc. A study has shown the general OR with the proper air purification method can also effectively control the number of bacterial colonies and dust in the air [28]. There have been rules for the construction of general ORs in China. The standard GB15982-2012 Hygienic Standard for Disinfection in Hospitals [34] defined clearly the environmental sanitation requirements of the general OR; the standard GB51039-2014 Code for Design of General Hospital [35] provided relevant regulations for the architectural design and heating, ventilation and air conditioning systems of the general OR; the standard WS/T368-2012

Management Specification of Air Cleaning Technique in Hospitals [17] had listed the air purification methods available for the general OR.

With the development of science and technology, new air purification methods are constantly appearing. The survey found that, in addition to ACT, the number of hospitals using circulating air UV sterilizers and electrostatic adsorption air sterilizers in ORs has been slowly increased year by year. Research has shown that using the dynamic air sterilizer in the OR can reduce the impact of personnel activity on air quality to a certain extent [36]. However, various temperature and humidity in different hospitals caused by the vast territory of China and the different density of personnel in different hospitals lead to that the disinfection effect of one air purification method in different

hospitals is diverse. The standard WS/T648-2019 General Hygienic Requirements for Disinfecting Machine [37] issued by Chinese government on March 1, 2019, made requirements for the disinfection effect of air sterilizers and further standardized the sanitary requirements for air sterilizers. Nevertheless, the air disinfection effect of one air purification method in various situations remains to be further studied. At the same time, we found ultraviolet light disinfection is still an important air disinfection method in ORs. Ultraviolet light disinfection has been proven to reduce the level of contamination in ORs and thereby preventing the SSI, but there are issues such as the frequency, amount, and locations for ultraviolet light disinfection needed to be further researched [16]. The survey also found that the use rate of circulating air UV sterilizers has gradually increased to 5.19% in 2017, which was close to that of ultraviolet light disinfection (5.84%). Studies have shown that there was no significant difference in the air disinfection effect between two purification methods under static conditions, but the total amount of microorganisms in the OR is rapidly increased under dynamic conditions after ultraviolet light disinfection [38, 39]. As mentioned above, air disinfection effects of different air purification methods are affected by a lot of factors, so further research is needed.

There are still many doubts about the selection of air purification methods. For example, there is no clear standard for situations requiring the construction of a COR, no rules for surgery type which can be operated in a general OR, and so on. All of the above issues require further research to provide scientific evidence-based evidence for the formulation and revision of national policies. Last but not the least, using air purification methods is just one of the ways to improve the air quality of the ORs. Strengthening the comprehensive management of the OR also plays an important role in improving and maintaining the quality of the air in the OR, including the development of the corresponding management system, controlling the number and the state of the personnel in ORs, the good management between surgeries, controlling the times and time of opening the surgical door, and cleaning and disinfection of the environment. [40–43]. Therefore, we should take comprehensive measures to improve the cleanliness of the OR and reduce the risk of SSI.

5. Conclusion

The number of hospitals using ACT in ORs has been increasing year by year. The rate of using different grades of CORs varies according to hospital level, region, and hospital type. Other air purification methods, including ultraviolet light disinfection, circulating wind UV sterilizer, and electrostatic adsorption air sterilizer also widely used in hospitals' ORs. How to correctly select and use different air purification methods is an urgent problem to be solved.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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