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*Original Article*

# Effectiveness of hospital disinfection: an experience leant from 11 years of surveillance

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**Abstract**

This survey was designed to assess the sanitation status of hospitals and the compliance of hospital staffs to disinfection strategies in the Chinese national hospital disinfection monitoring program within the past 11 years. A total of 199 provincial affiliated tertiary or secondary public hospitals from 2007 to 2017 were investigated and seven critical categories, namely indoor air, work surface, hand hygiene, ultraviolet (UV) irradiation intensity, use of disinfectants, sterilization of medical items, and effects of steam sterilizer, were monitored. The average qualified rates were (94.74±3.54)% (810/855), (97.25±1.65)% (1 876/1 929), (87.57±4.60)% (2 508/2 864), (95.00±4.50)% (1 196/1 259), and (98.76±1.14)% (1 599/1 619) for indoor air, work surface, hand hygiene, UV irradiation intensity, and sterilization of medical items, respectively. In terms of other categories, few samples were not qualified: 3/1 575 for use of disinfectants and 1/243 for effects of steam sterilizer. The hospital disinfection monitoring and supervision program effectively improved the effectiveness of disinfection. Routine monitoring and supervision must be conducted to ensure a safe hospital treatment environment.

**Keywords:** hospital disinfection, indoor air, hand hygiene, work surface, ultraviolet irradiation intensity, monitoring

## Introduction

Nosocomial infections are important contributors to morbidity and mortality[1], which have been an emerging threat to the health care system[2–3]. It is a prominent public health concern and is associated with mass economic burden. Nosocomial infections have been attributed to poor disinfection, decontamination, sterilization of hospital items, and implementation of antimicrobial stewardship policies. The measures often taken in preventing nosocomial infections include cleaning, disinfection, sterilization and the effective use of antiseptics and isolation of patients with highly infectious diseases.

The Chinese National Nosocomial Infection Surveillance System was established in 1986 in accordance to the International Nosocomial Infection Control Consortium (INICC)[4] and the members of this network are distributed in every province, municipality, and autonomous region. This marks a milestone in nosocomial management. A series of laws and regulations, such as technical standards for disinfection and management of nosocomial infections, were introduced in the 1990s, and the tasks and

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responsibilities of the hospitals were specified. Nosocomial infection cases were strictly registered and reported thereafter. With the advancement in nosocomial infections, hospital disinfection, one of the most critical strategies used in controlling nosocomial transmission, was included in the treatment management. Monitoring and supervision of hospital disinfection are important and are considered extremely crucial in understanding the roles played by hospital environment in the long-term prevention of nosocomial infections and transmission. Hospital environment may serve as reservoirs for these pathogenic microorganisms which are primarily transmitted through air, hand contact, and exposure to hospital articles.

To introduce detailed operative measures of our national monitoring program to the public and its influence on the changes in hospital disinfection conditions, we aimed to investigate the quality of indoor air, work surface, hand hygiene, UV irradiation intensity, sterilization of medical items, use of disinfectants, and effects of steam sterilizer.

## Materials and methods

The study was conducted according to the guidelines of the Hygienic Standard for Disinfection in Hospitals (GB15982-1995, GB15982-2012) and Architectural Technical Code for Hospital Clean Operating Department (GB50333-2002, GB50333-2013). In total of 199 provincial affiliated secondary or tertiary public hospitals were selected between 2007 and 2017. To assess the effectiveness of disinfection strategies used in hospitals, seven primary items, namely indoor air, work surface, hand hygiene, UV irradiation intensity, sterilization of medical items, use of disinfectants, and effects of steam sterilizer, were assessed.

### Indoor air sampling and laboratory testing

The plate exposure method was used to measure the depositing bacterial concentration, which is a cleanliness indicator of indoor air disinfection. Monitoring was conducted in the morning shortly after cleaning and disinfection and before clinical use according to the standard guidelines. The doors and windows were closed, and nobody was allowed to stay in the wards. For laminar flow wards, the operating and surrounding zones were assessed individually according to the cleanliness class (***Table 1***). The plates in the laminar flow wards were placed within 0.8 meter from the floor for 30 minutes. The assessment of the general wards was based on the size of the area ($m^2$). For general wards >15 $m^2$, the nutrient agar plates were placed 80 cm above the floor with one plate in the centre and four at the two diagonal lines of the room, and the plates were kept 1 meter away from the wall. While in wards sized <15 $m^2$, three points shaping a diagonal line were identified. The time for sampling was determined by the class the wards belong to (***Table 2***). Finally, the plates were covered and incubated for 24 hours (laminar flow wards) or 48 hours (general wards) at 37 °C. The total number of bacterial colonies was calculated as CFU (colony forming unit)/plate combined with corresponding time.

### Assessment of work surface and hand hygiene

The selected work surface included those with high-frequency contact with staffs and patients, which may be involved in cross-infection transmission routes[5] that are distributed throughout the treatment rooms of patients and sleeping areas, such as treatment vehicles, bench boards, bedside cabinets, and bed frames, which were mostly stainless steel or laminate plastics. A sterile cotton swab immersed in a neutralizing agent solution was used to wipe each sample (100 $cm^2$) on a defined square (5 cm×5 cm), and the cotton swab was rotated while wiping five times back and forth vertically and horizontally. The swab was vortexed in 10 mL phosphate-buffered solution with a neutralizing agent solution prior to being sown 1 mL in nutrient agar in duplicate. The total number of bacterial colonies (CFU/$cm^2$) after incubation at 37 °C for 48 hours was counted subsequently.

The sampling and testing of hand hygiene were similar to those of work surface with minor changes. The two fingers were wiped twice from the fingers to the fingertips by rotating the swab simultaneously. A total area of 60 $cm^2$ (30 $cm^2$ each hand) of each individual was sampled. The following steps were conducted in the same way as those in the work surface testing, and each sample of hand hygiene was expressed as CFU/$cm^2$.

### UV irradiation intensity, sterilization of medical items, use of disinfectants, and sterilization effects of steam sterilizer

The UV irradiation intensity was measured 1 m vertically by an UV irradiation meter with the light turned on for 5 minutes. The UV-C irradiation was performed at 254 nm and the minimum standard value for UV light was 70 μW/$cm^2$. The microbial contamination status of use of disinfectants was assessed to identify the total number of bacterial colonies. In total, 1 mL of disinfectant was added to 9 mL of corresponding neutralizing agent solution; this was then

***Table 1*** **Depositing bacterial concentration standards for laminar flow wards**

| Cleanliness class | Operating zone (CFU/30 minutes, φ90 plate) | Surrounding zone (CFU/30 minutes, φ90 plate) | Reference operation |
|---|---|---|---|
| Ⅰ | 0.20 | 0.40 | Implants, large organ transplants, surgical infections that can be life-threatening |
| Ⅱ | 0.75 | 1.50 | Large operation associated with deep tissue and vital organs |
| Ⅲ | 2.00 | 4.00 | Other surgeries |
| Ⅳ | 6.00 | | Infection and severely polluted surgery |

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***Table 2*** **Standard benchmarks of indoor air, work surface, and hand hygiene**

| Class | Environmental area | Indoor air | Work surface | Hand hygiene |
|---|---|---|---|---|
| Ⅰ | Laminar flow wards | See Table Ⅰ | ≤5.0 CFU/cm² | ≤5.0 CFU/cm² |
| | Other general clean wards | ≤4.0 CFU (30 minutes, φ90 plate) | | |
| Ⅱ | General wards, delivery room, baby room, premature infant room, general protective isolation room, sterile area of supply room, burn ward, and intensive care unit (ICU) | ≤4.0 CFU (15 minutes, φ90 plate) | ≤5.0 CFU/cm² | ≤5.0 CFU/cm² |
| Ⅲ | Paediatric ward, gynaecological examination room, injection room, dressing room, treatment room, cleaning area of supply room, emergency room, laboratory, all kinds of ordinary wards, and rooms | ≤4.0 CFU (5 minutes, φ90 plate) | ≤10.0 CFU/cm² | ≤10.0 CFU/cm² |
| Ⅳ | Infectious disease section and ward | ≤4.0 CFU (5 minutes, φ90 plate) | ≤10.0 CFU/cm² | ≤10.0 CFU/cm² |

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vortexed and inoculated 1 mL in nutrient agar in duplicate and incubated at 37 °C for 72 hours. The total number of bacterial colonies (CFU/mL) was counted and the benchmark of disinfectant for mucus should be ≤ 10 CFU/mL, whereas that of other disinfectants must be ≤ 100 CFU/mL. Sterile medical supplies were randomly selected for aseptic testing, and any microbiology testing was not permitted. The effect of steam sterilizer was detected using *Bacillus stearothermophilus* spore processed through a steam autoclave cycle and incubated for 7 days to obtain the readout.

### Statistical analysis

The results were evaluated according to the standards (***Tables 1*** and ***2***). The data were transferred to Excel and STATISTICA 17.0 software (StatSoft Inc.). The qualified rates of indoor air, work surface, hand hygiene, UV irradiation intensity, and sterilization of medical items were analysed using the nonparametric comparative Chi-square test. A $P$ value of < 0.05 was considered significant. The data on use of disinfectants and the effect of steam sterilizer were analyzed descriptively.

## Results

Over the 11-year period, a total of 855 indoor air, 1 929 work surface, 2 864 hand hygiene, 1 259 UV, 1 619 sterilized medical items, 1 575 use of disinfectant, and 243 steam sterilizer samples were collected. The annual average qualified rates of indoor air, work surface, hand hygiene, UV, and sterilized medical items were (94.74±3.54)%, (97.25±1.65)%, (87.57±4.60)%, (95.00±4.50)%, and (98.76±1.14)%, respectively (***Table 3***). Differences in hand hygiene ($\chi^2$=49.37, $P$<0.001) and UV ($\chi^2$=79.67, $P$<0.001) qualified rates were highly significant and variable, and the qualified rate for hand hygiene varied from 80.79% to 93.73%, and this was considered as the most variable factor. The differences in the other three items were less variable, with rates all > 90%. In addition, few microbiological contaminated items were noted in disinfectant (3/1 575) and steam sterilizer (1/243). Overall, the data from this program indicated the effectiveness of hospital disinfection was improved by monitoring and administrative supervision over these years.

***Table 3*** **Annual monitoring qualified rate of indoor air, work surface, hand hygiene, UV, and sterilized medical items**

| Year | Indoor air | Work surface | Hand hygiene | UV | Sterilized medical items |
|---|---|---|---|---|---|
| 2007 | 91.67 (110/120) | 95.34 (327/343) | 80.79 (307/380) | 85.14 (212/249) | 98.13 (157/160) |
| 2008 | 90.65 (97/107) | 97.00 (226/233) | 87.61 (304/347) | 97.44 (152/156) | 100.00 (179/179) |
| 2009 | 92.08 (93/101) | 99.00 (199/201) | 86.18 (262/304) | 95.18 (158/166) | 96.97 (160/165) |
| 2010 | 94.74 (90/95) | 97.09 (167/172) | 89.85 (292/325) | 93.75 (150/160) | 98.74 (157/159) |
| 2011 | 94.44 (102/108) | 99.47 (189/190) | 93.73 (269/287) | 100.00 (165/165) | 99.44 (177/178) |
| 2012 | 95.56 (43/45) | 98.55 (136/138) | 92.56 (224/242) | 96.36 (53/55) | 96.95 (127/131) |
| 2013 | 100.00 (83/83) | 96.32 (183/190) | 88.65 (289/326) | 98.61 (142/144) | 99.48 (190/191) |
| 2014 | 100.00 (71/71) | 96.13 (149/155) | 80.77 (189/234) | 100.00 (93/93) | 100.00 (154/154) |
| 2015 | 98.21 (55/56) | 97.24 (141/145) | 90.43 (170/188) | 100.00 (40/40) | 98.00 (147/150) |
| 2016 | 93.18 (41/44) | 100.00 (100/100) | 91.11 (123/135) | 100.00 (17/17) | 98.98 (97/98) |
| 2017 | 100.00 (25/25) | 95.16 (59/62) | 82.29 (79/96) | 100.00 (14/14) | 100.00 (54/54) |
| Total | 94.74 (810/855) | 97.25 (1 876/1 929) | 87.57 (2 508/2 864) | 95.00 (1 196/1 259) | 98.76 (1 599/1 619) |
| $\chi^2$ | 18.87 | 16.68 | 49.37 | 79.67 | 15.50 |
| *P* | 0.042 | 0.082 | <0.001 | <0.001 | 0.115 |

Note: qualified rate (qualified samples/total samples).

## Discussion

The national hospital disinfection monitoring and supervision program provides uniform standard guidelines for health care settings in China. Surveillance reports of provincial, municipal, or other given hospitals based on the program written in Chinese were published with consistent results each year. The findings of our surveillance were similar to most of the literatures[6–8]. Overall, a significant improvement was observed over the years. The best hygienic measures were use of disinfectants, sterilization of medical items, and effect of steam sterilizer, mostly with 100% qualified rates. The disinfection effectiveness of work surface and hand hygiene was less satisfactory, with a qualified rate of 80%–95%, and the situation was even less satisfying in primary health care settings.

Air: Laminar flow operating room, general operating room, ICU, delivery room, and neonatal wards that belong to class Ⅰ and Ⅱ cleanliness were monitored for indoor air. A total of 855 samples were collected with a qualified rate 94.74% (810/855), and the difference of the qualified rate was statistically significant ($\chi^2$=18.87, *P*=0.042). The disinfection effectiveness of laminar flow rooms was better than that of the general operating rooms, which was attributed to the governmental enforced intensified heavy investments in the infrastructure construction of public hospitals during the past decades. As a result, laminar flow operating room in hospitals is becoming popular, which further improves the disinfection quality of the operating room and reduces the risk of hospital infection. It is worth mentioning that the unqualified rates of delivery room, outpatient clinic, and steri lization supply room were relatively high, which may be related to the constancy of the use of the delivery room and clinic. Surgical site infection is the second most common health care-associated infection as one of the risk factors for such infection is bacterial contamination of operating rooms[9]. Common air disinfection techniques include the use of UV light, air disinfection machine, and laminar flow technology. UV light is widely used in outpatient and sterile supply rooms. However, its use is becoming less popular in the delivery room in big hospitals in recent years as it was substituted with the use of air disinfection machine and laminar flow technology owing to the fact that the latter meets the requirement of air disinfection and treatment activities. The techniques used in air disinfection and treatment activities must be urgently introduced in clinics, particularly in respiratory transmitted disease clinics, which may significantly contribute to reducing the risk of hospital infection.

Work surface: The cleaning and disinfection of critical surfaces in hospitals are essential in reducing microbial contamination and nosocomial infection[10]. Although there are no internationally accepted criteria for defining a surface as clean using microbiologic methods, some investigators have suggested that microbial contamination should be 2.5 to 5 $CFU/cm^2$[11–12], which is the most commonly accepted indicator of good hygiene. Our national hospital hygiene monitoring system has listed specific work surfaces, which are frequently touched by the medical personnel and patients, and thus may potentially increase the risk of acquiring hospital infection. Treatment vehicle, operation desk, neonatal incubator, and bedside tables in wards are usually selected. To avoid bacteriostatic or bactericidal interference of residual disinfectant, a neutralizing agent is used in surfaces and during hand hygiene and disinfectant in-use testing.

Hand hygiene: The average qualified rate was 87.57%, which was the lowest among the seven monitoring projects. After being monitored for 11 years, the hand hygiene level has improved, and we have observed significant changes in the compliance of most medical personnel to hand hygiene requirement. Hand hygiene in operating rooms, ICU, and delivery rooms had a higher qualified rate than that in other departments, owing to the emphasis enforced by the institution. However, unqualified hand hygiene in delivering rooms, rooming-in wards, and neonatal units was still observed annually. There was a lower awareness and compliance about hand washing in sterile supply rooms, outpatient clinics, and laboratories. Great efforts must be exerted to improve the level of hand hygiene awareness and compliance as cross-infection is a potential threat to these departments. As indicated in several studies, hand hygiene plays a critical role in reducing nosocomial infection[13–16]. Thereby, increased supervision helps in improving the health awareness and compliance of medical staffs.

UV irradiation intensity: The UV irradiation intensity improved over the years. With regard to the use of UV light, lacks of cleaning and overuse were the problems concerned. A lamp should be kept clean to release irradiation and be substituted when the UV irradiation decreases below the standard level. At the beginning of our surveillance around 10 years ago, the staff were not fully informed about UV light maintenance, and the lights used then were often unqualified. Nowadays, the regular monitoring of the UV radiation intensity by the hospital ensures the effectiveness of UV disinfection. Continuous shielded UV at the room level may reduce infectious cases[17], and irradiation intensity should be routinely monitored to guarantee enough irradiation dosage.

Use of disinfectants, sterilization of medical items and effects of steam sterilizer: povidone iodine, 75% ethanol, and chlorhexidine acetate were the most commonly used disinfectants for hand and skin hygiene. Before 2008, 2% iodine and iodine tincture were commonly used in clinics, whose use declined with the popularization of povidone iodine due to its superiority on disinfecting effectiveness, duration, and absence of adverse reactions, such as skin irritation. The disinfectant, commonly used for endoscopy, enteroscopy, and bronchoscopy, is 2% glutaraldehyde, while few other disinfectants have been used to replace glutaraldehyde even to date. The use of o-phthalaldehyde is suggested in some countries, and has been used sporadically in a few hospitals in our province.

The sterilized medical items that were assessed were mostly operating tools and sterilized disposable articles. Aseptic testing showed that microbiological contaminated items were primarily cotton swabs, disposable syringes, and disposable dental instrument boxes, which were sterilized by the manufacturers using ethylene oxide or hydrogen peroxide gas plasma. Some sterilized medical items, such as disposable syringe, were directly used during the treatment of patients with trauma, which indicates that the items contaminated with bacteria causes an emerging risk of nosocomial transmission. Hence, the use of sterilized medical items must be strictly regulated.

Among the 243 cases of steam sterilizer assessment, only one failed during the testing in the first year. Gravity displacement and vacuum-assisted steam sterilizer were commonly used in clinics. Flash sterilization, low temperature sterilization, or sterilization using ethylene oxide gas and hydrogen peroxide gas plasma, were used in several health care settings. However, they were not included in our annual monitoring program. According to the monitoring report in other provinces[18–20], most of the steam sterilizers produced ideal qualified rate, which indicated that the efficiency of sterilization was guaranteed in hospitals.

The survey provides comprehensive insights into hygienic conditions of provincial affiliated secondary or tertiary public hospitals in Guangxi, and the results of the present study showed a significant improvement in the disinfection strategies of hospitals after the implementation of the health monitoring and supervision program. Moreover, we observed compliance changes among the staff over the years, and infection control officers of the hospitals undertake routine surveillance. It must be noted that regular cleaning and surveillance might be the most effective strategies in reducing nosocomial infections.

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