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Original Article

Efficacy of infection control pathway in reducing postoperative infections in patients undergoing neurosurgery

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Abstract
Introduction: The environment of the operating room (OR) is closely related to the postoperative complications of patients, and it is necessary to study, to what extent, the stringent management of the OR can reduce postoperative complications.
Methodology: 426 patients who underwent surgery between January 2016 and December 2017 were selected from two class-100 laminar flow ORs of equivalent area, and were divided into an experimental group and a control group.
Results: The experimental group had significantly lower total air-borne bacterial count in the OR than the control group 10 minutes before surgery (6.21 ± 4.14 *vs*. 11.58 ± 5.36 CFU/cm^3), 10 minutes (15.67 ± 6.21 *vs*. 20.83 ± 5.78 CFU/cm^3), 30 minutes (27.34 ± 8.18 *vs*. 39.56 ± 7.86 CFU/cm^3) and 60 minutes (43.62 ± 7.66 *vs*. 51.63 ± 8.43 CFU/cm^3) into surgery, and at the end of surgery (57.34 ± 7.67 *vs*. 69.33 ± 9.41 CFU/cm^3) (all $p < 0.05$). The incidence rates of increased body temperature and leukocyte count 3 days post-surgery, and the duration of antibiotic therapy and hospital stay were significantly reduced in the experimental group compared to the control group (all $p < 0.05$). Furthermore, the total number of pathogens in the incision at 2 hours into surgery was also significantly lower in the experimental group than in the control group ($p < 0.05$).
Conclusion: Stringent application of the infection control pathway is an efficacious measure for improving the air cleanliness of the neurosurgery OR, decreasing the incidence rates of postoperative complications and infection, as well as controlling pathogen transmission.

Key words: operating room; postoperative infection; infection control, air cleanliness.

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Introduction

The operating room (OR) is one of the most important clinical departments responsible for the critical tasks of saving patients' lives and first aid. Therefore, maintaining a sterile OR environment with clean air is critical for the prevention of infection [1,2]. The air disinfection quality in the OR is of great importance, since a failed disinfection can impose adverse effects on the patients [3,4]. The OR infection refers to infectious diseases caused by direct or indirect invasion of pathogenic microorganisms into the patients. Patients who undergo neurosurgery are more susceptible to postoperative infections, since they usually have critical conditions and varying degrees of consciousness disorder, while the surgical treatment is difficult and long. Operation-related infections can impose tremendous pain and heavy financial burden on patients during their rehabilitation. Such infections may even threaten the life of patients, which has a serious impact on the efficacy of surgery and rehabilitation [5]. Therefore, the air in the neurosurgical OR must be stringently disinfected and monitored to ensure a sterile surgical area, which is important for reducing the risk of surgical complications [5–7]. In this work, a prospective randomized controlled study was conducted using the clinical data of patients who underwent neurosurgery in an OR that adopted the infection control pathway to identify risk factors that influence postoperative infections and to provide objective insights into the development of nosocomial infection prevention and control measures. The aim of the present study was to examine the efficacy of the infection control pathway in reducing nosocomial infection, in order to improve the safety management of the OR.

Methodology

Data collection

A total of 426 patients who underwent neurosurgery in our hospital between January 2017 and December

2018 were randomly divided into a control group (n = 213) and an experimental group (n = 213). In the control group, there were 119 males and 94 females with a mean age of 41.85 ± 1.042 years (19 to 54 years). In the experimental group, there were 112 males and 101 females with a mean age of 42.04 ± 1.015 years (22 to 57 years). Type of surgery: The control group and the experimental group included 175 and 182 cases of intracranial space-occupying meningioma and glioma, 21 and 17 cases of trigeminal microvascular decompression, and 17 and 14 cases of intracranial aneurysm clipping, respectively. There were no significant differences in the general conditions, staffing, and types of surgery between the two groups by using t test, Chi-square test or Fisher's exact test (all $p > 0.05$), indicating that the two groups were comparable (Table 1). The patients of both groups signed the informed consent form and the study was approved by the Ethics Committee of our hospital (ref. 2015-1024).

Patients in the control group were given conventional care before, during, and after surgery. Patients in the experimental group were given conventional care along with an infection control strategy. The neurosurgical OR was thoroughly cleaned by the same cleaning personnel before and after the implementation of the infection control pathway. The surgical instruments were sterilized in the same way, and the medical staff used the same infection prevention and control (IPC) measures and personal protective equipment (PPE). In the control group, the air was sterilized by the automatic filtration function of the class-100 laminar flow OR, whereas in the experimental group, the air was sterilized by the class-100 purification system and the stringent infection control pathway. The details of the process are as follows: Items in the OR were routinely cleaned and disinfected after each surgery, followed by the implementation of the infection control pathway: (1) Establishment of a specialized OR infection control team. This team consisted of a specialist team leader, a supervisor nurse, and two nurses. The team members were highly experienced in nursing and were trained to be familiar with infection prevention in the OR. This team was responsible for the stringent management of all infection control procedures, and any violating action would be immediately corrected. (2) Strict control of the entry and exit of the medical staff and strict implementation of the dress code. The OR remained closed at all times and visitors or people suffering from skin or respiratory infections were prohibited from entering the OR. (3) Noise reduction in the OR by gentle actions. (4) Patients were advised to remain clean and hygienic, and the possibilities of skin, digestive tract, respiratory tract, and urinary infections were inquired before surgery. Emphasis was given to the proper skin preparation at the surgical site. (5) The bacterial count from the hands of the medical staff before surgery was determined, and should be less than 5 CFU/cm^2. (6) The automatic air filtration system in the class-100 laminar flow OR was regularly inspected to ensure optimal air purification. The filter should be regularly replaced and cleaned by designated personnel, and inspection should be reinforced to ensure the OR air cleanliness. Air quality was also monitored by a specialist on a monthly basis. (7) OR instruments and environment were monthly monitored by the infection control team to ensure that microorganisms were absent in the endoscope and the sterilization after disinfection, the intensity of the ultraviolet lamp was ≥ 70 μW/cm^2, the number of bacterial colonies in the OR was ≤ 4 CFU/cm^2, and the number of pathogenic microbes on the OR staff after disinfection was ≤ 4 CFU/cm^2.

The collection and detection of bacterial specimens was conducted in strict accordance with the “National Guide to Clinical Laboratory Procedures". Air samples were collected in the OR 10 minutes before surgery, 10

Table 1. Cohort characteristics by study group.

Characteristic	Control group (n = 213)	Experimental group (n = 213)	p
Gender (N, %)			**0.496**
Male	119 (55.9)	112 (52.6)	
Female	94 (44.1)	101 (47.4)	
Median age, years	41.85 ± 1.04	42.04 ± 1.02	
Diagnosis			
Intracranial space-occupying	175	182	0.357
Trigeminal microvascular decompression	21	17	0.497
Intracranial aneurysm clipping	17	14	0.576
Median operative time, minutes (IQR)	188.2 ± 7.45	181.9 ± 6.66	0.527
History of diabetes	26	18	0.721
Previous surgery	1	3	0.623

IQR ¼ interquartile range.

Table 2. Air disinfection quality comparison between the two groups (CFU/cm^3).

Group	Number of patients	10 minutes before surgery	10 minutes into surgery	30 minutes into surgery	60 minutes into surgery	At the end of surgery
Control group	213	11.58 ± 5.36	20.83 ± 5.78	39.56 ± 7.86	51.63 ± 8.43	69.33 ± 9.41
Experimental group	213	6.21 ± 4.14*	15.67 ± 6.21*	27.34 ± 8.18*	43.62 ± 7.66*	57.34 ± 7.67*
t-value		2.073	2.309	2.217	2.326	2.644
p-value		0.047	0.044	0.041	0.036	0.030

* $p < 0.05$ compared to the control group.

min, 30 min, and 60 minutes into surgery and at the end of surgery. For bacterial culture and identification, the surgical site was swabbed 10 mins before disinfection and bone residues were collected after 2 hours in surgery. *Staphylococcus aureus* (ATCC25923) and *Escherichia coli* (ATCC8739) from the National Center for Clinical Laboratories were used as quality control strains. Bacterial strain identification was performed using the VITECK-2COMPACT automatic microbial identification system (BioMerieux, Marcy l'Etoile, France). The results were recorded and analyzed by the APILAB software (France).

Outcome

The incidence of surgical site infections (SSI) within 30 days of operation , the OR disinfection efficacy, body temperature 3 days post-surgery (≥ 37.3°C) was considered elevated body temperature), white blood cell count (≥ 10.0×10^9), postoperative antibiotic therapy duration, time of stitch removal, incidence rate of postoperative infection, and pathogen distribution were compared between the two groups.

Statistical analysis

Continuous data are expressed as mean ± standard deviation and were compared using the Student's t-test, while categorical data are expressed as number and percentage and were compared using the Chi-square test or Fisher's exact test. All tests were 2-sided, and $p < 0.05$ was considered as statistically significant. For statistical analyses, the software Prism (version 7.00; GraphPad, La Jolla, California, USA) were used.

Results

Air disinfection quality

The experimental group had a significantly lower number of bacterial colonies in the OR than the control group 10 minutes before surgery, 10 min, 30 min, and 60 minutes into surgery and at the end of surgery (all $p < 0.05$) (Table 2).

Postoperative condition

The experimental group had significantly lower incidence rate of increased body temperature, SSI within 30 days of operation and increased leukocyte count 3 days post-surgery, shorter duration of postoperative antibiotic therapy and hospital stay, and later stitch removal than the control group (all $p < 0.05$) (Table 3).

Pathogen distribution

No significant difference was found between the control and the experimental group in the number of bacterial strains detected before disinfection. However, after 2 hours in surgery, the experimental group had a significantly lower number of bacterial strains than the control group (Table 4).

Discussion

OR infection is the most critical and potentially the most dangerous component of nosocomial infections [1,5,8,9]. Therefore, effective and stringent infection prevention management during surgery is extremely important for the prevention of OR and even nosocomial infections. According to relevant clinical data, the incidence rate of nosocomial infections has

Table 3. Postoperative condition comparison between the two groups.

Group	Number of patients	Increased body temperature (n, %)	Increased leukocyte (n, %)	Number of SSI[a] (n, %)	Antibiotic use (n, %)	Time of stitch removal (d, $\bar{x} \pm s$)	Hospital stay (d, $\bar{x} \pm s$)
Control group	213	35 (16.43)	127 (59.62)	8(3.76)	102 (47.89)	7.43 ± 0.20	9.83 ± 0.32
Experimental group	213	11 (5.16)	96(45.07)	1(0.47)	44 (20.66)	9.00 ± 0.66	8.83 ± 0.31
Statistics		$\chi^2 = 13.92$	$\chi^2 = 9.043$		$\chi^2 = 35.06$	t = 2.294	t = 2.301
p-value		0.0002*	0.0026*	0.0371*	0.0000*	0.0407*	0.0442*

[a]SSI, surgical site infections.

Table 4. Comparison of pathogen distribution at the incision site between the two groups.

Bacterial isolates	Number of strains detected before disinfection (n, %)		Number of strains detected during surgery (n, %)		p-value*	p-value*
	Control group	Experimental group	Control group	Experimental group		
Corynebacterium	30 (46.15)	33 (57.89)	15 (51.72)	5 (45.45)		
Acinetobacter baumannii	21 (32.31)	19 (33.33)	8 (27.59)	3 (27.27)		
Staphylococcus aureus	11 (16.92)	3 (5.26)	2 (6.90)	1 (9.09)		
Staphylococcus epidermidis	3 (4.62)	2 (3.51)	4 (13.79)	2 (18.18)		
Total	**65**	**57**	**29**	**11**	**0.391**	**0.003**

*Comparison of the number of bacterial strains detected before disinfection between the control and experimental groups; #Comparison of the number of bacterial strains detected after 2 hours into surgery between the control and experimental groups.

been increasing in recent years and OR infection has always been the most common type [10]. This high prevalence of OR infection is mainly due to the more critical condition of patients undergoing neurosurgery, the extent of trauma caused by surgery, and the interference by emotional and psychological factors. The fact that the patients have a weakened immune response and that various invasive procedures are performed during the surgery, can increase the risk of OR infection in these patients, making them a high-risk population for infections. Once OR infection develops, it not only exacerbates the patient's condition and affects the efficacy of the surgery, but also it increases the medical resource consumption and treatment costs. Hence, reducing the incidence rate of OR infection is of great significance for health care and patient welfare.

Many factors can lead to OR infections. Common causes include poor ventilation in the OR, long surgery times, frequent opening and closing of the OR door, frequent visitors, frequent entry and exit of medical personnel, and the use of foreign materials [11]. The air in the OR contains dust, cotton wool, skin cells, and respiratory droplets, which can all be potentially contaminated by bacteria [10,12]. Studies have shown that increased frequency of OR door opening and staff movement reduces the efficiency of the ventilation system and significantly increases air pollution [12–15]. In addition, compared to sliding doors, hinged doors have a greater risk of air pollution [16]. The ventilator in the laminar ventilation system provides high-quality air to the OR, and the number of bacterial colonies in areas close the surgical site is very low [7,17,18]. Continuous maintenance and assessment of the laminar ventilation system is very important, since a failure in the system can impose adverse effects on the air quality and endanger the safety of the patients during surgery [17]. In this study, the entry and exit of the medical personnel was strictly controlled, the OR door was kept closed, visitors were prohibited, and the automatic filtration system of the class 100 laminar flow OR was regularly inspected to ensure optimal air purification. In addition, the filter was regularly replaced and cleaned by designated personnel along with reinforced inspection to ensure the air cleanliness in the OR. Air quality was also monitored on a monthly basis by a specialist. These measures demonstrated satisfactory results in the air quality control in the OR. In general, the hands of the surgeon are colonized by many bacteria, and the surgeon is at risk of persistent infection by Gram-negative bacilli, *Staphylococcus aureus*, and fungi due to repeated exposure to such pathogens. These pathogens can then be transmitted to the patient and cause infections [19]. In this study, the number of bacteria on the hands of the medical staff was determined prior to surgery. Surgeons with $\geq$ 5 CFU/cm^2 on their hands before surgery were prohibited from participating in the surgery, which effectively eliminated intraoperative infection of the hands.

The impact of the dress code on the prevention of postoperative infection is still under debate. Studies have shown that the type of scrub cap does not affect the incidence rate of postoperative infection, and hence it is not mandatory for the OR [20–24]. However, many studies still support the development of a dress code for the OR and believe that it is beneficial for the prevention of postoperative infections [25]. This study followed the dressing suggestions for the OR issued in 2015 by Association of Perioperative Registered Nurses (ARN) [26,27]. It is also believed that a strict dress code is useful for preventing postoperative infections.

High-risk *Staphylococcus aureus* sequence type is a hyper transmissible, strong biofilm-forming, antibiotic-resistant, and virulent genotype that frequently appears in OR environments [28]. Patient skin surfaces and provider hands are confirmed sources, while the surfaces in the OR are confirmed transmission locations [28]. In order to determine the bacterial source and type and effect of intervention, the bacteria collected from the incision sites of the control and experimental groups were compared and it was found that, before disinfection, gram-negative bacilli were the predominant scalp bacteria (78% and 91%, respectively) followed by gram-positive cocci (21% and 9%, respectively). No significant difference in the total number of bacteria-positive cases was found between the two groups (p = 0.86). Under the intervention of the infection control pathway, the experimental group had a significantly lower total number of bacteria than the control group (p = 0.026), indicating that reducing the possible transmission routes of bacteria helps to control bacterial reproduction and growth around the surgical site. The bacteria distribution may be closely associated with pathogens that originate from the skin flora and iatrogenic transmission. Longer operative times were indeed associated with higher rates of contamination, and operating under laminar airflow appeared to be protective only during the first 90 minutes following incision [18]. The results of the present study demonstrated that the collection of specimens after 2 hours in surgery is indeed helpful for determining the effect of the intraoperative air environment on the bacteria distribution around the incision. It was also found that the application of the infection control pathway significantly reduced the number of bacteria and prevented postoperative infections and complications.

Although the infection control pathway is often avoided by most surgeons and anesthesiologists, due to its inconvenience during actual practice, its application can significantly improve the efficacy of air disinfection in the neurosurgical OR, reduce the incidence rate of postoperative complications and especially infections, and eliminate the possible sources of infection in the OR. Therefore, the infection control pathway is an efficacious measure for ensuring patient safety.

Conclusion

In this case-control study, we examined the quality of air infection in the neurosurgery OR and postoperative condition of the patients after application of the stringent infection control pathway. We isolated and cultured potential pathogens from the surgical incision and determined the distribution of the bacteria. Our results demonstrated that the infection control pathway is an efficacious measure for improving the air cleanliness of the neurosurgery OR, decreasing the incidence rates of postoperative complications and infection, as well as controlling pathogen transmission.

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