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Effect of Electronic Air Filtration Technology on Air Quality in Operation Rooms (Cairo-Egypt)

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Abstract:
Background: *Hospital environmental control procedures can be an effective support in reducing health care associated infections.* ***Aim:*** *Assessment of the effectiveness of electronic air filtration (A novel air filtration device) in improving air quality in operating room of pediatric surgery department, Ain Shams University Hospitals.* ***Methodology:*** *This study was divided into 2 phases, Phase I: Descriptive study: assessment of air quality in operating rooms at pediatric surgical hospital, the evaluated air quality indices were: suspended particulate matter, culture media and microbial identification of bacteria and fungi using active and passive air sampling. Phase II: Interventional study for improving air quality by new electronic air decontamination unit (Genano® 4500).* ***Results:*** *After intervention the operation room moved up from (ISO 8) to (ISO 6) there is a highly statistical significant difference between particulate matter count before and after intervention also there is significant difference in active bacterial sampling and fungi sampling before and after applying electric filtration device where fungal colony count dropped significantly to zero. All virulent bacterial species as E.Coli, klebsiellaspecies and Pseudomonas Aeroginosa. disappeared from sample with few micrococci and bacillus species were preset in few samples.* ***Conclusion:*** *the importance of electronic filtration as an effective method to improve air quality in OR, hence reducing morbidity and subsequent mortality that could occur to the patients due to poor air quality in the operating theaters.*
Keywords: *Air quality, Electronic filtration, Microbiological air sampling, Operating rooms.*

Introduction:

Surgical site infection (SSI) is one of the most common Healthcare Associated Infection (HAI), estimated to account for 18.6% of inpatient HAI (Berriós-Torres ***et al.***, 2017)

In Egypt, A study was carried out on 292 patients recruited from those admitted to the General Surgery Department of Tanta University Hospital for elective surgery during a period of 6 months. The patients were examined for the development of SSI during the postoperative hospital stay showing overall incidence of SSI of 22.6% (Afifi ***et al.***, 2009).

In 11 Egyptian hospitals, 510 surgical site infections (SSIs) following 4246 surgeries were identified with overall SSI rate of 12%. SSI rates

observed following each surgery were laparotomy (22.9%), thoracic surgery (21%), abdominal hysterectomy (10.6%), cardiac surgery (9.3%) and craniotomy (2.5%). 66.3% were superficial SSIs, 28.2% were deep SSIs and 5.5% were organ/space SSIs (Abduo *et al.*, 2016).

The source of SSI can result from the skin organisms prior to surgery, from surgical instruments, from the environment during surgery; or during provision of care post surgery. The SSIs are the most preventable of all HAI(Salcedo, 2018).

Operating room air may contain microbial-laden dust, lint, skin squames, or respiratory droplets. (Mangram *et al.*, 1999). Outbreaks of SSIs caused by group A beta-hemolytic streptococci have been traced to airborne transmission of the organism from colonized operating room personnel to patients. In these outbreaks, the strain causing the outbreak was recovered from the air in the operating room (Gryska and O'Dea, 1970).

Ishida *et al.* (2006) reported that air borne bacteria in the environment are thought to be a cause of postoperative infection. Jiménez *et al.* (2004) evaluated the presence of bacteria in environment of an oncological service of national hospital, Surfaces, such as carpets, potted plants and multiple-hole false ceilings are potential sources of fungal contamination. Dust might accumulate in these areas and spores may enter the patient room as contaminants on personnel's clothing.

In particular, the environmental matrices (water, air and surfaces) play a leading role as reservoirs of microorganisms: e.g. *Legionella* spp. And *Pseudomonas aeruginosa* are often isolated from water samples in hospital facilities; *influenza A* virus and other viruses from air; spores of filamentous fungi from surfaces in operating theatres (Services, 2014).

The ventilation system is responsible for keeping good indoor air quality (IAQ) and also for ensuring infection control in the OR and other sterile processing, i.e. to protect the patient from becoming infected.

In accordance with (Burkhead *et al.*, 2015), the environment plays an important part in infection prevention and control. For this reason, it is considered that the evaluation of environmental cleanliness to be an integral part of any infection prevention and control program.

Therefore the use of an in-room air cleaner to reduce the concentration of airborne pathogens and prevent the spread of airborne infectious diseases has been proposed as an alternative to renovating a HVAC system (Health Quality Ontario, 2005).

A mechanical air cleaner uses a mesh of material, usually fiberglass fibers, to trap particles passing through them. They both impede the particles and attract them to the surface of the fibers, where they become lodged. The most common type of mechanical air cleaner is the HEPA (high energy particulate air) filter (Vijayan *et al.*, 2015). However, these can create too much blockage against airflow. Unlike mechanical air cleaners, electronic cleaners are not filters at all. Instead, they create an electric field that ionizes particles passing through it. When the particles are ionized, they are drawn and attracted to a positively charged plates inside the cleaner and trapped there. Electronic air cleaners require an external power source to run, but they are often necessary because their unique technology removes even the smallest impurities from indoor air. These impurities can consist of DNA

fragments, viruses, bacteria, mould spores as well as traffic originated soot that is too small for a mechanical filter to catch (**Ekaterina, 2011**).

Electronic air cleaners don't have traditional fiber filters, so there is no risk for a breeding ground to microbes forming inside the unit even in humid conditions. An activated carbon filter is used for the removal of harmful gases and ozone.

Controlling airborne pathogens in healthcare facilities is not only important for the safety of patients, but it is also important for hospital personnel. If any person inhales the airborne particles, their fate will depend on many factors i.e. small particles can reach the most distant parts of the respiratory tract while particles larger than 5 mm diameters, easily adhere to the mucus membranes of the upper respiratory tracts. Continuously moving cilia guide the particles to the throat, where they are removed by coughing or swallowing .

Through air sampling, it is possible to evaluate microbial contamination in environments at high risk of infection. Moreover, these controls can be used to check the efficiency of both the Conditioned and Controlled Ventilation System (CCVS) and the team's hygiene procedures.

For this reason, hospital environmental control procedures can be an effective support in reducing health care associated infections (**Services, 2014**).

The current study aims at assessment of the effectiveness of electronic air filtration (A novel air filtration device) in improving air quality in operating rooms.

METHODOLOGY:

Study Design:

This study was divided into 2 phases:

- Phase I: Descriptive study.
- Phase II: Interventional study.
- **Phase I: Descriptive Study:**
- Assessment of air quality in operating rooms at pediatric surgical hospital through:
- a- Measuring the amount of Particulate matter (before the intervention)
- b- Bacterial Sampling (before the intervention)
- **Phase II: Interventional study**
- 1- Intervention for improving air quality by new electronic air decontamination unit (Genano® 4500).
- 2. Assessment of air quality through analysis of air samples that will be taken after implementation of the decontamination unit and compared by the results of air analysis before intervention by the same methods.
- **Sampling site** The intervention was performed in one OR of pediatric surgery department, Ain Shams University Hospitals, they have 3 ORs.

In operating room, sample was taken each time, when the room is resting (not operating) early in the morning at 8:00 am.

During the sampling period, indoor air was conditioned but not heated. A ceiling-mounted high efficiency particulate air (HEPA)-filtered laminar air flow with 15 air changes per hour (ACH) supplied the operating theater area but in some rooms an additional conventional air conditioning system was added as the main HVAC (heating, ventilation, and air conditioning).The HEPA filters are changed annually and were last changed

two months before sampling in the current study.

The operating room Conventional (mixing) ventilation system is used as it is an old hospital; the mixing ventilation operates based on the principle that supplied air mixes relatively rapidly with the existing air in the room. The air supply diffusion system is located symmetrically on the ceiling and the air is flowing in an uncontrolled manner and is subject to direction changes as in (Table 1) showing that relative Humidity is WITHIN the standard range while Temperature, Differential pressure value and Air Change per hour were OUT of the standard range.

Limitation of the study: the sampling of air was done in the presence of mixed ventilation in the operation rooms, so that air quality may be affected adversely during the intervention phase.

Table (1): Operation Room (OR) measurements and ventilation system values:

Operating Room Values			Comparison with standard values
Air change per hour (ACH)	times	15.6	About 0.6 of the recommended value (25 times)
Grand Total Supply	m3/h	1560	Air supply needed (2500)
Grand Total Extraction	m3/h	0	Air extraction needed (1800)
Pressure	Pa	4	-3 Below the minimum value (7-15)
Grand Average Temp	Celsius	26	+ 2 C above the max. value (21 – 24)
Grand Average Humidity	%	45	Within the range (45-55)

➢ **Study time:**

All samples of air quality indices were done between April 2017 and April 2018.

Air quality Monitoring:

i- Location: Settle plates, the particulate matter air sampler and Single-Stage Viable Andersen Cascade Impactor were located next to patient bed and nearest ventilation vent in operating room (**Cristina *et al.*, 2012**), As shown below:

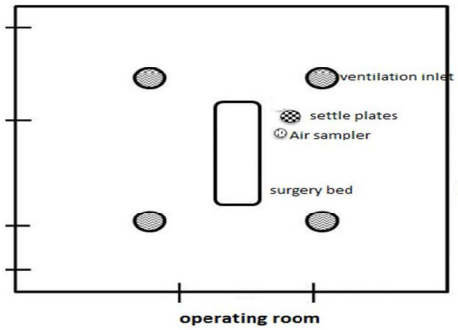

Fig (1) Location of Settle plates, the particulate matter air sampler and Single-Stage Viable Andersen Cascade Impactor inside the operating room.

ii- The evaluated air quality indices were:

- Suspended Particulate Matter (PM) Levels were measured using a portable

dust monitor (Air Quality monitor, EG Air, U.S.A.).

- Culture media and microbial identification of bacteria and fungi.
- Temperature and relative humidity (RH) using a digital thermometer and hygrometer (BT-2, china).
- International Organization for Standardization (ISO) values were used for comparison with its standards (*ISO 14644-1:2015 - Cleanrooms and associated controlled environments -- Part 1: Classification of air cleanliness by particle concentration*, 2015).

iii- Microbial air sampling and culture technique:

In active monitoring, a microbiological air sampler (Single-Stage Viable Andersen Cascade Impactor) physically draws a known volume of air through or over a particle collection device which can be a liquid or a solid culture media where the quantity of microorganisms present is measured in CFU (colony forming units)/m3 of air. This system is applicable when the concentration of microorganisms is not very high, such as in an operating theatre and other hospital controlled environments

Passive sampling was performed to determine the Index of Microbial Air Contamination (IMA) (**Placencia AM, 1984**). This index corresponds to the number of CFU counted on a Petri dish with a diameter of 9 cm placed according to the 1/1/1 scheme (for 1 hour, 1 m above the floor, about 1 m away from walls or any major obstacles).

The CFU values obtained by passive method were converted to their respective IMA values (**Pitzurra, Savino and Pasquarella, 1997**) and the maximum acceptable level of IMA in OTs with a turbulent air flow was taken to be <5 CFU/9 cm diameter plate/h at rest and <25 CFU/9 cm diameter plate/h in operation (**Napoli, Marcotrigiano and Montagna, 2012**). The CFU values for active method were modified and expressed as CFU/m³ based on the conversion table given by the manufacturer. Maximum acceptable level taken as standard during active sampling, as per Istituto Superiore per la Prevenzione e la Sicurezza del Lavoro (ISPESL) 2009 guidelines, for microbial contamination in OTs with turbulent air flow were <35 CFU/m³ at rest (**Imai *et al.*, 2008**).

Bacterial plates were incubated at 25℃ for 48 h for growing environmental bacteria (the great majority of species) and at 37℃ for 48 h for growing mesophilic bacteria (human related species). Fungal plates were incubated at 28℃ for 5–7 days. Positive hole correction was applied to the raw colony forming unit (CFU) of active sampling ad recorded on each plate, and by using the CFU with sampling time and flow rate, the microbial concentrations were calculated and expressed as colony forming unit per cubic meter (CFU/m³) of the air (**Osman *et al.*, 2018**).

Nutrient agar (NA) (LABM Limited, Lancashire, UK), supplemented with 100 mg/L cyclohex-amide was used for the sampling and cultivation of bacteria (**Obbard and Fang, 2003**).

For isolation of fungi, Sabouraud dextrose agar (SDA) (LABM Limited, Lancashire, UK), supplemented with 10 mg/L chloramphenicol was used (**Rainer, Peintner and Pöder, 2001**). Blood agar (BA) supplemented with 5% sterile blood, NA and BA were incubated at 37°C for 48 h to allow the growth of aerobic bacteria.

Bacterial colonies were initially characterized by microscopic appearance and morphology and identified then by

gram staining and biochemical reaction tests (J.G. Collee, R.S. Miles, 1996).

A wet mount preparation of each fungal colony was prepared by using Lactophenol-cotton blue solution and examined microscopically. Identification of fungi was mainly based on growth colonies appearance, microscopic examination of the spore and hyphael characterstics of the stained preparations (Samson RA, Hoekstra ES, Frisvad JC, 2002).

All laboratory tests were carried out at microbiology department in Faculty of Medicine, Ain Shams University, Cairo, Egypt.

- - Intervention for improving air quality by using electronic air decontamination unit
- Genano® 4500 is a new premium air decontamination unit developed by the Finnish hi-tech company Genano Ltd. The new Genano 4500 delivers up to 450 m3 of ultrapure air in an hour. The unit has versatile settings for easy use. Genano 4500 uses Genano Technology® which is able to capture all particle sizes down to nanosized particles (1 nm = one millionth of a millimeter), eliminate microbes and viruses, and remove gases and odours. Genano 4500 has been designed and manufactured in EU, Finland.
- Statistical Analysis: Data were processed and analyzed using SPSS version 20.0 (Statistical Package for Social Science) software. The results were analyzed in terms of descriptive statistics, and the relationships between variables were tested by univariate analyses (HARRIS &TAYLOR, 2014).
- Ethical considerations: The study protocol was approved from the ethical committee of Faculty of Medicine Ain Shams University. Ain Shams University Pediatric Surgery department administrative approval was obtained.

Results:

According to the airborne particles count, the operation room studied is classified as (CLASS ISO 8) before intervention with mean and Standard deviation of particulate matter shown in (table 2), ISO 14644 standards establish classes of air cleanliness for airborne particulate levels in cleanrooms and associated cleanroom areas, (clean zones) including critical environments in hospitals and other healthcare facilities.

After intervention the operation room moved up to (ISO 6) and by applying paired-t test to compare particulate matter means as shown in (table 2), there is a highly statistical significant differences between particulate matter count before and after intervention in all values except PM 2.5µ\m³.

Table (2): Particle μ's Count at the operation room (OR) before and after intervention

Particulate Matter*	Mean	Std. Deviation	Particulate Matter	Mean	Std. Deviation	Paired-t test	P-value
PM0.3before	218090	19590	PM0.3after	103000	8000	-16.956	.015* 0
PM0.5before	72715	2685	PM0.5after	32725	2675	-6926.471	0.000**
PM1before	9425	25	PM1after	5305	400	-19.029	0.003*
PM2.5before	5750	3300	PM2.5after	2655	195	-1.726	0.226
Pm5before	585	105	PM5after	261	35	-6.640	0.015*
PM10before	240	60	PM10after	109	1	-3.846	0.006*

*significant results **highly significant results

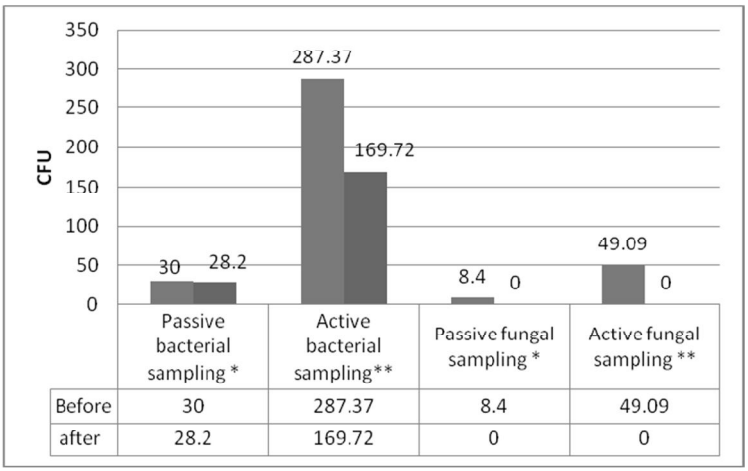

Fig (2) means of colony forming unit in active and passive methods before and after intervention.

**concentration measured as colony count per Petri dish*

** *Colony forming unit per cubic meter*

Table (3): Paired-t test to compare means of bacterial and fungi count using active and passive air sampling before and after intervention in the OR

Passive microbiological air sampling			
		Paired-t test	P-value
Pair 1	Passive bacterial sampling before	0.108	0.919
	Passive bacterial sampling after		
Pair 2	Passive fungal sampling before	4.220	0.013*
	Passive fungal sampling after		

Active microbiological air sampling			
		Paired-t test	P-value
Pair 1	Active bacterial sampling before	2.925	0.043*
	Active bacterial sampling after		
Pair 2	Active fungal sampling before	4.661	0.010*
	Active fungal sampling after		

*Significant result

At rest the OR exceeded the maximum limit value of the passive sampling for Colony Forming Unit count (<5 CFU/9 cm diameter plate/h). While in active sampling there is significant difference in bacterial and fungi counts before and after applying electronic filtration device.

Table (4): Comparison between the microbiological species present before and after intervention

Microbiological species	Before intervention	After intervention
klebsiellaspecies	+ +	-
E.coli	+ +	-
Pseudomonas Aeroginosa	+ +	-
Micrococcispecies	+ +	+
Bacillusspecies	+ +	+
Diphtheroids	+ +	-
Aspirigillus.niger	+ + +	-
Asp.flavus	+ + +	-
Aspirigillusfumigatus	+ + +	-
Penicillium	+ + +	-
Candida Albicans	+ +	-

Bacterial species isolated from the plates were as follows: Micrococci species, Bacillus species and Diphtheroids which were found in 100% of samples before but decreased markedly after intervention, while harmful species like klebsiella species, Pseudomonas Aeroginosa and E.coli disappeared completely after intervention.

Fungi present before intervention were; Aspirigillus fumigatus, Penicillium, Aspirigillus niger, Asp.flavus, and Candida albicans. After intervention all sampling plates showed no growth of fungi.

Discussion:

The current study aimed at measuring quantitatively the microbial and particulate matter contamination in operating room theatre at pediatric surgery department in Ain Shams University Pediatric Hospital, also to find out how useful is the electronic air filtration mechanism in improving air quality indices.

This study showed that Particulate Matter concentration in all study samples

before intervention were above the WHO standard levels. Similarly, in Saudi Arabia, a study done by El Sharkawy and Noweir (2014) found that levels of PM (both PM_{10} and TSP) were higher than the Air Quality Guide (OR 313.92 microgram/m^3).

In the current study, the airborne particle cleanliness classification of operating theatres was ISO 8 during rest unlike results of a study done in Finland where they studied air and surface hygiene in four Finnish operating theatres, the air cleanliness with laminar supply was found to be ISO class 6 due to control problems in the ventilation systems when it was resolved it went down to ISO class 5 (Wirtanen *et al.*, 2012).

This poor ISO classification of pediatric surgery OR could be attributed to the old central air conditioning system and flowing of air in an uncontrolled manner in addition to direction changes, in spite of the fact that there is HEPA filter installed. But after intervention with GENANO device, the operation room moved up to (ISO 6) which is a breakthrough despite the fact that we weren't able to connect all operating theatre air inlets with Genano filtration devices, so the Genano system could not work with its full capacity.

High concentration of bacteria found in the current study settings agrees with results of a study by Singh (Singh, 2013) in which higher bacterial contamination was found in air samples instead of surface or article sample, and the maximum growth of contaminated bacteria was observed in General Surgery ward. The place representing the higher risk of skin infections, boils, wound infections or abscesses.

The current study investigated only one sampling point located nearly1 meter away from the surgical table as recommended by the (Cristina *et al.*, 2012)and in this position, all samples from OR before intervention exceeded the limit values. A study done by Napoli, Marcotrigiano and Montagna (2012) revealed that levels of recorded microbial contamination in operating rooms are influenced by external factors such as the point of collection in the operating room. In the light of this study sampling near the wound would have probably resulted in higher colony counts. This confirms previous reports in which, using passive sampling method, higher microbial counts were found on settle plates in operating rooms nearer the wound than away from it (Friberg and Burman, 1999).

By using passive air sampling technique to evaluate microbial contamination, results of the current study showed that all air samples from all studied areas before intervention in Ain Shams Univesity Pediatric Surgery department were positive for growth of bacterial colonies. Unlike in Sudan, out of 79 samples that were collected from delivery rooms at different hospitals, 52 of them (63.3%) showed positive bacterial growth (O. Yagoub and El Agbash, 2010).

By using active air sampling technique to evaluate microbial contamination, pre intervention mean bacterial CFU count was above the allowable level, but after electronic filtration it dropped significantly, also fungal colony count dropped significantly to zero after intervention.

Before intervention, six species of Bacteria were isolated from the studied settings and showed that *micrococci species, bacillus species, diphtheroids* were present in both active and passive

air sampling plates. While *E.Coli*, *klebsiellaspecies and Pseudomonas Aeroginosa* were found by active sampling only .The presence of these highly pathogenic bacteria in air samples of OR increases the risk for patients undergoing surgical operations to acquire surgical site infections (**Dharan and Pittet, 2002**). Also Mirzaei *et al.*(**2014**) in his study detected 17 types of bacteria were the most detected bacteria were *Micrococcus* and *S. aureus* in both emergency and operating rooms.

It is worthy to state that after intervention, all virulent bacterial species as *E.Coli*, *klebsiellaspecies and Pseudomonas Aeroginosa* disappeared from all samples with few micrococcus and bacillus species were preset in few samples.

Before intervention, five species of fungi were isolated from the studied settings and showed that *aspirigillus niger, asp.flavus aspirigillus fumigates and penicillium* were present in all active and passive sampling plates while *candida albicans* were found in active sampling only. All these fungi disappeared completely after intervention and the plates showed no fungal colony growth.

Conclusion:

The results of this study should direct the attention of hospital infection control and quality teams to the importance of electronic filtration as an effective method to improve air quality in OR, hence reducing morbidity and subsequent mortality that could occur to the patients due to poor air quality in the operating theaters, which directly contribute to safer health care and enhancement of patient safety.

CONFLICTS OF INTEREST: The authors declare that no conflicts of interest exist.

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