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# Association between air changes and airborne microbial contamination in operating rooms

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ABSTRACT

*Background:* Control of airborne microbial contamination is important in operating rooms (ORs). To keep airborne contamination low, guidelines should highlight the importance of air turnover. The aims of the study were: (1) to verify the association between air turnover and airborne contamination in ORs; and (2) to identify a statistical relationship between air turnover and airborne microbial contamination.

*Methods:* A cross sectional study was carried out from November 2014 to July 2017 in the teaching Hospital of Siena. Nineteen ORs (14 with turbulent and 5 with laminar flow ventilation) were surveyed a total of 59 times under operating conditions. Air samples were collected with an air sampler. Petri dishes, incubated at 36 °C for 48 h, were used to quantify colony forming units in the samples (CFU). The data was transformed to evaluate several statistically significant nonlinear associations between air turnover, quantified as air changes per hour (ACH) and CFU per cubic meter of air ($p < 0.05$).

*Results:* A log-linear regression model provided the best fit between ACH and CFU for laminar ($p = 0.013$; $R^2 = 0.3911$) and turbulent flow systems ($p = 0.002$; $R^2 = 0.3443$). The corresponding model was: ln(CFU) = (a − b*ACH), where the regression parameters were estimated at a = 4.02 and b = 0.037 for laminar flow and a = 5.24 and b = 0.067 for turbulent flow.

*Conclusions:* Italian guidelines indicate microbial load limits of 20 and 180 CFU/m$^3$ for operating rooms with laminar and turbulent flow ventilation, respectively. The model allowed us to evaluate the minimum number of ACHs to keep CFU within these limits. Ad hoc measurements in other environments can be used to calibrate the relationship between ACH and CFU.



## Introduction

Operating room (OR) conditions may influence the outcome of surgery, affect patient safety, influence operating team comfort, and may produce suboptimal clinical conditions. Certain OR parameters, such as the pressure gradient between the operating room and the outside, the amount of particulate in the air, microbiological contamination of surfaces and air (CFU/m$^3$), air turnover and type of airflow (laminar or turbulent), are regulated by guidelines delineating limits and references values [1]. Air turnover in ORs is measured in air changes per hour (ACH). There is no universal minimum reference number of ACH [2]. In some countries, such as Italy, a minimum is set at 15 ACH [1]. In the United States, it ranges from 15 to 20, depending on the type of operating room [3].

Although no direct association between airborne microbial contamination and surgical wound infection has been demonstrated [4], it is generally accepted that higher airborne microbial contamination levels would increase surgical site infection (SSI) rates [5]. SSIs are a common cause of healthcare-associated infections (HAIs) and postoperative infection occurs in 0.6–9.5% of surgical procedures, depending on the type of surgery [6]. Each year in Europe, six major causes of HAIs (healthcare-associated pneumonia, healthcare-associated urinary tract infection, healthcare-associated *Clostridium difficile* infection, healthcare-associated neonatal sepsis and healthcare-associated primary bloodstream infection and SSIs) lead to a burden of disability-adjusted life-years estimated at 501 per 100,000 of the

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general population [7]. There are about 2,600,000 new cases of HAIs per year, 800,000 of which are SSIs, which therefore have the highest incidence of the six: 156.5/100,000. The mortality/morbidity due to SSIs is estimated at 58.2 DALYs/100,000 [7]. The financial burden of SSIs is roughly 33% of the 8.5 million spent on HAIs every year [8].

Several studies focus on the relation between laminar or turbulent flow and microbial contamination of air [9] and surgical wounds [5,10]. According to Fischer et al., a laminar airflow ventilation system costs 24% more than the turbulent flow option [11], but lowers airborne bacterial contamination [12]. However, a recent systematic review found that unidirectional airflow does not have benefits with respect to turbulent flow ventilation. Indeed, other authors found that using laminar airflow during hip prosthesis procedures increased the risk of SSIs [4].

Since little is known about possible associations between ACH and airborne microbial contamination, we set out to determine whether type of airflow can affect the OR environment.

The aims of the present study were: (1) to determine whether the reference value of 15 ACH ensures an airborne bacterial contamination levels below 180 CFUs/m$^3$ and 20 CFUs/m$^3$ for turbulent and laminar flow ventilation, respectively; (2) to create a model to predict airborne microbial contamination on the basis of ACH.

## Methods

This cross-sectional study was performed from November 2014 to July 2017 in 19 ORs of the Teaching Hospital of Siena "Le Scotte". The ORs we studied are equipped for different kinds of surgery: three for orthopedics and emergency surgery, two for gynecological surgery, four for general surgery, seven for neurosurgery and heart surgery and three for eye surgery. Room volumes range from 74 m$^3$ to 164 m$^3$, and their layouts is practically the same: there is a sliding door on one side and the operating table and anesthesia boom are in the center. Fourteen ORs have turbulent and the other five have laminar flow ventilation. We made 59 surveys in these ORs under operating or simulated operating conditions. In the ORs with laminar with laminar flow ventilation the inlets are disposed to form a central plenum vent in the ceiling of the three orthopedic/emergency ORs and on a wall in the gynecology ORs. ORs with turbulent flow ventilation have four vents positioned at intermediate distances between the wall and the in the center of the ceiling.

We determined colony forming units (CFUs) using a Microflow alfa active air sampler (AQUARIA srl, Italy) with 55-mm diameter RODAC plates containing plate count agar. For each survey we collected 1 m$^3$ of air (in four consecutive samplings of 0.25 m$^3$, one around near in each corner of the OR, at a flow rate of 120 cm$^3$/min). The Microflow alfa was positioned 1.5 m above floor level and about 1 m from each corner in order to obtain a representative sample of the air in each OR. A single sample of 1 m$^3$ from only one point would be less representative of the OR. The sampling was conducted by specialist medical staff and the plates were incubated for 48 h at 36 °C. The number of ACH was calculated dividing the volume of air fed into the OR per hour (m$^3$/h) by the volume of the OR. The volumetric flow rates of air into the ORs was measured with a balometer (Testo 420, Testo AG, Germany).

Descriptive statistics of the parameters of interest were calculated. For the quantitative variable "number of CFUs per cubic meter of air" we calculated mean, standard deviation (SD), median and interquartile ranges (IQR). To look for an association between CFUs and ACH, we used a linear regression model which we fitted to the natural-logarithm of CFUs, ln(CFUs), against ACH. We used an exponential model because it provided a normal distribution of CFU measurements, facilitating statistical analysis. The trade-off between data variability and correctness of statistical model was acceptable ($R^2 < 0.4$). Statistical analysis was performed with the statistical software package Stata Version 14 (StataCorp, USA). Statistical significance was set at $p < 0.05$.

## Results

Forty-four out of 59 samples (75%) were obtained under conditions of turbulent airflow and the other 15 (25%) under laminar flow. The number of ACH ranged from 5.3 to 59.9, median 16.3, IQR 11.9–23.1. In ORs with laminar flow ventilation, ACH ranged from 15.1 to 59.9, median 41, IQR 22.1–45.3; in ORs with turbulent flow ventilation, ACH ranged from 5.3 to 27.6, median 15.4, IQR 11.1–17. In ORs with laminar flow ventilation, CFUs/m$^3$ were in the range 0–47, median 12, IQR 7–39; in ORs with turbulent flow ventilation, CFUs/m$^3$ were in the range 10–259, median 71, IQR 39.5–43.5.

After logarithmic transformation of CFUs, the best fitting models for ORs with laminar ($p = 0.013$; $R^2 = 0.391$) and ORs with turbulent flow ventilation ($p = 0.002$; $R^2 = 0.344$) had coefficients of the independent variable, ACH, of −0.037 (constant 4.017) and −0.067 (constant 5.235), respectively. When the results were back transformed, we obtained two exponential equations to predict CFUs from a given ACH, with e4.02+(−0.037*ACH) and e5.24+(−0.067*ACH), for laminar and turbulent flow, respectively. Figs. 1 and 2 show the scatter plot of ACH vs CFUs and the expo-

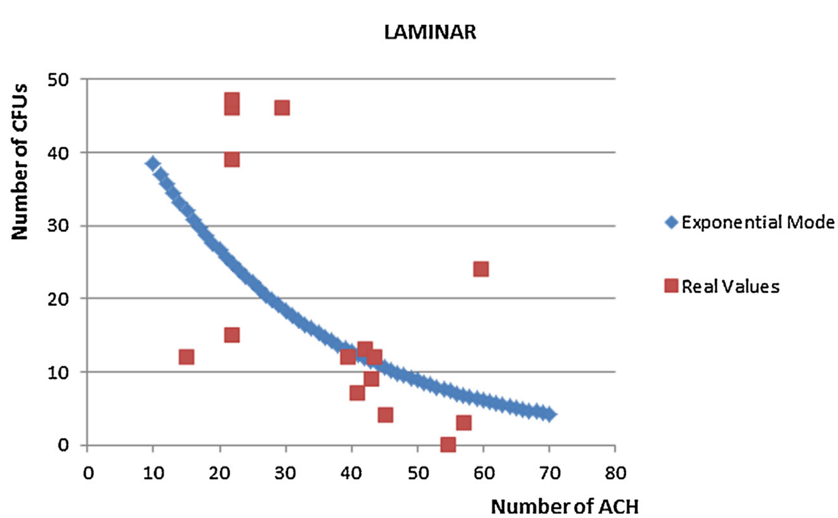


**Fig. 1.** Scatter plot of ACH vs CFUs and exponential fitting model for ORs with laminar airflow.

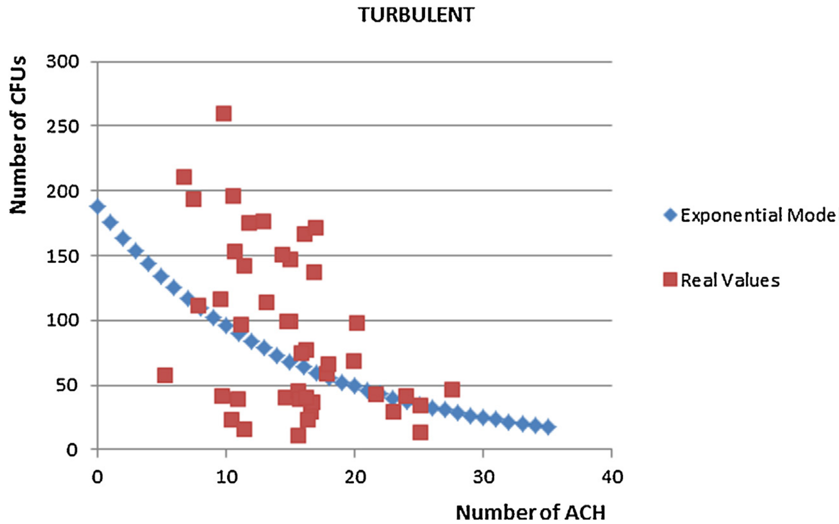


**Fig. 2.** Scatter plot of ACH vs CFUs and exponential fitting model for ORs with turbulent airflow.

nential fitting model for ORs with laminar and turbulent airflow, respectively.

## Discussion and conclusions

In this study, we modeled the association between airborne microbial contamination and air turnover in operating rooms. As expected, contamination decreased with increasing air turnover. Although the model was moderately fitting ($R^2 < 0.4$), it estimated the minimum air turnover needed to maintain a contamination level compatible with the guidelines [1]. The regression model indicated that at the reference value of 15 air changes per hour (ACH), the number of CFUs per cubic meter of air was about 30 in ORs with laminar flow ventilation and 50 in those with turbulent flow ventilation. Laminar airflow was associated with fewer CFUs than turbulent flow ventilation (medians of 12 CFUs/m$^3$ and 71 CFUs/m$^3$, respectively). However, according to ISPSL guidelines [1], 15 ACH are amply sufficient to remain below the limit of 180 CFUs in ORs with turbulent ventilation, but they are not sufficient for ORs with laminar flow ventilation, which should be below 20 CFUs.

The implications for the study are several-fold. First, for ORs with laminar flow ventilation, the reference value of 15 ACH [1] should be increased, so that airborne microbe count remains below the 20 CFUs/m$^3$ limit. Second, for ORs with turbulent flow ventilation, the reference value of 15 ACH [1] could be lowered without reaching the reference airborne microbe count of 180 CFUs/m$^3$. The guidelines should consider that the design of ventilation systems may change over time. Indeed new ORs should be designed differently to improve ventilation.

Our model presumably has several applications to the construction or development of new ORs or in any environment requiring the regulation of air flow patterns. However, it is still useful for monitoring average airborne microbial contamination and for notifying when critical levels are exceeded. Where it is possible to carry out measures similar to those reported in this study, another log-linear model with different regression coefficients can be used.

There are several limitations to this study. First, the amount of data collected on the laminar airflows was limited and may have influenced the results of our model, although continuous monitoring of the ORs will increase the number of samples and strengthen the model. Second, we did not record other data, such as the number of members of the operating team, which could influenced airborne microbial contamination. Although the material on human behavior may seem tangential, it is important and future research should study the dynamics of team composition on airborne bacterial load. Indeed, Agodi et al. commented that "It is essential to increase healthcare workers' awareness of the risk associated with incorrect behavior in ORs" [13]. Third, we did not consider possible obstruction of air vents, which could affect airflow.

In summary, we developed a methodology to establish the airborne bacterial load in ORs with laminar and turbulent airflow. The methodology developed in this paper provides a framework to better understand the factors affecting airborne microbial contamination in the OR.

Future studies should analyze the postoperative course of patients for SSIs, so as to define a link between airborne bacteria and SSIs, and hence between air turnover and SSIs, and not just between air turnover and airborne bacteria.

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## Competing interests

None declared.

## Ethical approval

Not required.

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