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Review Article

Role of Ventilation in Controlling Surgical Site Infections

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Abstract...

Surgical Site Infections (SSIs) are the major cause of nosocomial infection. Sometimes it creates many health hazards among healthcare staff, patient and inmates of hospital. In this COVID-19 pandemic it is necessary to have a clean surgical atmosphere, proper ventilation inside the hospital as well as the space dedicated for surgery. So routine SSI examination and cleaning of surgical area following proper guideline is necessary. The proper ventilation should be provided to the surgical space for creating healthy environment for surgical procedure without secondary infection. In this review SSI and role of ventilation has been discussed.

Keywords: Surgical site infections; Covid19; Ventilation.

Introduction

Corona Virus Disease 2019 (COVID-19) has once again brought worldwide attention to infectious diseases, following the outbreaks of SARS and influenza H1N1 viruses in China. One of the most common means of infection transmission is the release and dissemination of pathogens such as viruses, bacteria, and fungus into the atmosphere [1]. Surgical Site Infections (SSIs) can occur if airborne germs infiltrate a patient's open wounds in the Operating Room (OR), where a clean air environment is critical to preventing infection. In both Europe and the United States, SSIs rank as the second most common source of Healthcare-Associated Infections (HAIs) [2]. As much as 15% of high-risk patients may develop SSIs when they are exposed to contaminated procedures in emergency trauma surgery [3-5].

Surgical site infections (SSIs)

Surgical site infections continue to be one of the most common causes of significant surgical complications [6], accounting for 14-17 percent of all hospital-acquired infections and 38 per-

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cent of nosocomial infections in surgical patients [7,8]. When compared to operational patients without an SSI, each SSI is associated with roughly 7-10 more postoperative hospital days, and patients with an SSI have a 2-11 times higher risk of death [9,10].

Elderly patients with SSIs caused by *Staphylococcus aureus* had a higher risk of mortality (odds ratio - OR: 5.4) and more post-operative hospital days in a nested-cohort research conducted in a 750-bed tertiary-care hospital in North Carolina, US (2.5-fold increase) [11].

Hospital stays, mortality rates, and health-care costs are all significantly increased by SSIs. Because to SSIs, the length of a hospital stay can be extended by 9.7 days on average, with each additional stay costing around $20,000 [12]. The mortality rate associated with SSIs might approach 3% [13]. The amount of particles and bioaerosols in the air environment is positively associated to the risk of infection, according to relevant literature [14,15]. SSIs, in particular, can be superficial infections affecting only the skin. Other surgery site infections can be more dangerous, affecting tissues beneath the skin, organs, or implanted materials. According to the Centers for Disease Control and Prevention, there are three forms of surgical site infection like superficial infections, deep incisional infections, and infections involving organs or body spaces. Surgical site infection is influenced by the degree of surgical site contamination at the time of operation. Wounds are classed as “clean wounds,” “clean-contaminated wounds,” “contaminated wounds,” or “dirty or infected wounds” depending on the existence and degree of contamination [16-18].

Many researches have looked at infection rates in the four surgical classes. Prior to the widespread use of antibiotic prophylaxis, the rates were around 1-2 percent for clean wounds, 6-9 percent for clean-contaminated wounds, 13-20 percent for contaminated wounds, and 40% for unclean wounds. Because bacterial burden is the most significant risk factor for SSIs, prophylactic antibiotics have significantly lowered this risk [19], particularly for surgical procedures with a high risk of infection, such as gastrointestinal procedures [20].

Microbiology

The germs isolated from infections vary depending on the surgical method. *Staphylococcus aureus* from the patient’s skin flora is the most common source of infection in clean surgical operations, in which the gastrointestinal, gynecologic, and respiratory systems have not been penetrated. The exposed tissues are at risk of infection by endogenous bacteria when mucous membranes or skin are incised [21]. *S. aureus* is responsible for 20 to 30 percent of surgical-site infections, with the endogenous flora accounting for more than half of these [22]. Anderson et al. reported a total of 1,010 SSIs in 26 hospitals after 89,302 procedures; *S. aureus* was the most often isolated organism, with 331 (37%) of SSIs recovered. Methicillin-Resistant *Staphylococcus Aureus* (MRSA) caused 175 (53 percent) of the 331 *S. aureus* SSIs, making it the most often isolated pathogen [23]. In addition, recent investigations have revealed that reduced sensitivity to vancomycin and other glycopeptides is emerging in various MRSA clones around the world [24,25].

The polymicrobial aerobic and anaerobic flora closely approaching the typical endogenous microflora of the surgically resected organ are the most often isolated pathogens in other types of surgical procedures, including clean-contaminated, contaminated, and dirty [26]. Exogenous sources of harmful germs include the operating room environment, surgical personnel [27], and all tools, instruments, and materials introduced into the sterile region during an operation. Staphylococcus aureus, coagulase-negative staphylococci, Enterococcus spp., and *Escherichia coli* are the most often isolated species [28,29]. Giacometti et al. [30] looked at 676 surgery patients who presented with signs and symptoms of wound infections over the course of six years. 614 people were tested for bacterial infections. There was a significant amount of aerobic microorganisms present. *Staphylococcus aureus* (28.2%), *Pseudomonas aeruginosa* (25.2%), *Escherichia coli* (7.8%), *Staphylococcus epidermidis* (7.1%), and Enterococcus faecalis (7.1%) were among the most prevalent pathogens (5.6 %) [31].

Source of contamination

Characteristics of airborne particles

Microorganisms that cause contamination might be endogenous or external. Because the skin is a reservoir of endogenous germs, proper preoperative skin preparation is critical. Airborne particles, the staff (hands, other regions of the skin, and mucous membranes), and, more rarely, inanimate objects (instruments, material, furnishing, or irrigation solutions) transmit exogenous microorganisms [32]. In only 2% of cases, the patient’s skin is the direct source of contamination, leaving 98 percent of cases to airborne particles [33]. Surgical-site contamination by airborne particles is attributed to direct settling on the wound in 30% of instances and settling on the tools and surgeon’s hands followed by transfer to the wound in 70% of cases [34]. As a result, airborne particles, some of which may carry bacteria, are primarily responsible for surgical-site contamination. Given the importance of airborne pollution in the OR, air quality should be closely monitored.

Particles in the air arise from a variety of sources, the most important of which is the shedding of squames, or skin scales. An individual with a moderate degree of physical activity sheds particles with a diameter of at least 0.5 mm every 10 minutes on average. Squames circulate via convection currents caused by the temperature difference between the body and the environment, despite their great size [35]. Dust and condensation droplets smaller than N5 in diameter, which are the leftovers of bigger droplets created during coughing, talking, and suction systems, are other sources of airborne particles. The tendency of particles to settle on surfaces is influenced by their size. Particles less than 5 mm remain floating in the air, those bigger than 100 mm settle quickly, and particles in the middle (5-100 mm) may land on potentially contaminated surfaces before migrating to other locations. Depending on their source, particles may carry a variety of bacterial burdens. The number of people in the OR has an impact on particle production and mobilisation. Another consideration is whether the surgical clothes provide an adequate barrier against squames shedding into the OR air: Squames can move from exposed flesh (e.g., the neck and forearms) or via gaps in the surgical garments’ material (e.g., 80 for woven cotton) [36]. Particles can be mobilised by any movement in the OR. Because patient installation necessitates human displacements and other motions, airborne particle concentrations are highest at the start of the operation [37]. The use of a cautery, which produces tiny and ultrafine particles, and the use of saws or drills are among the many other sources of particles [38].

Controlling airborne particle circulation necessitates meticulous attention to operating room discipline, surgical technique, and operative time. Air can serve as a reservoir for bacteria as well as a vector for the transmission of bacteria via particles (such as dust and squames) or condensation droplets smaller than 5. The aetiology of SSIs is complicated by contamination by airborne bacteria. Knowledge of the most commonly encountered microorganisms and their dissemination properties is required to prevent contamination by airborne germs. Furthermore, knowledge of air quality parameters, measuring tools, and treatment strategies is essential.

Air quality control

Parameters of air quality

The air quality in OR is assessed using a number of measures. According to an ISO standard, the airborne particle count at rest is used to classify ORs. The ISO 5 criteria, i.e. 3500 particles/m^3, must be met by orthopaedic ORs. The degree of microbial contamination, i.e., the CFU count per m^3 of air determined by injecting air samples into nutrient agar, then identifying and counting the colonies; the extent of microbial contamination, i.e., the CFU count per m^3 of air determined by injecting air samples into nutrient agar, then identifying and counting the colonies.

Air purification techniques

The air treatment procedures utilised have an impact on the air quality. The air delivery and filtration system, the features of OR air changes, and the presence of positive pressure in comparison to nearby areas are all important considerations.

Air filtering and delivery systems: The idea is to build a dynamic barrier around the at-risk area by generating a guided flow of filtered air that transports the particles away while maintaining a sufficient air change rate [33,39].

Air filtration: currently available filters filter out particles larger than 0.5 microns;

Airflow: There are three types of airflow:

Air is given through outlets on one wall and aspirated by exhausts on the opposing wall in a turbulent flow. This system generates non-parallel airflows, most notably at the instrument tables and surgical site, as well as two forms of unidirectional flow: Air moves in a single direction across a clean room or area, in parallel flows and at a consistent rate. The flow might be horizontal or vertical, and it can be partial (limited to the surgical table surface) or total (covering the entire operating room).

Various airflow rates are used: Rates near to or larger than 0.50 m/s are necessary to achieve a downwards laminar flow at the surgical site, surrounding the area at most risk; rates less than 0.25 m/s create a stable flow.

Changes in air: The air change rate, which is measured in number of air changes per hour, is another essential characteristic. The smallest figure that is permissible is 20% of total air volume per hour. It's crucial to think about the size of the ceiling air outlets. The volume of fresh air delivered is determined by the surface area of these outlets as well as the delivery rate. Due to the abnormally tiny surface area, a high delivery rate is required, resulting in noise levels that are difficult to bear [40].

Positive pressure: To reduce turbulence during door openings, the OR must have a sufficient and steady rise in air pressure (at least 15 Pa) compared to nearby sites.

Kinetics of particle decompression: This characteristic is defined as the time required to return a specific room laden with dust particles to 90% of the particle count measured with the ventilation system on (according to pre-established parameters).

During surgery, air quality is determined by a mixture of air treatment measures (filter, delivery, modifications, and positive pressure) as well as personnel-related aspects (number of individuals in the OR, surgical attire, and behaviours [41].

Ventilation

A ventilation system and indoor air distribution not only maintains indoor temperature and humidity and improves the thermal comfort of the occupants but also provides a clean environment for occupants [42]. There is a strong correlation between the ventilation system and the concentration of air contamination, and an effective ventilation system can significantly reduce the incidence of infection [43]. The most commonly used ventilation in an operating room is laminar airflow ventilation. In laminar airflow ventilation, a large area air supply diffuser provides a uniform flow of clean airflow through the surgical area to remove microbial contaminants from the surgical area. In reducing airborne bacteria, many studies have shown that laminar airflow ventilation is more effective than turbulent mixed airflow ventilation, which is based on the principle of dilution [44-46]. Laminar airflow ventilation includes Vertical Laminar Airflow (VLAF) ventilation and Horizontal Laminar Airflow (HLAF) ventilation. In VLAF ventilation, the airflow passes through a high-efficiency air filter on the ceiling and then flows along parallel streamlines at high velocity and low turbulence through areas where the surgical field and sterile objects are exposed. Although the flow pattern is not an exact laminar airflow, the highly powered airflow will continue to carry away the BCPs produced by the surgical staff. Many experimental studies and numerical simulations have demonstrated that the VLAF system effectively protects the operating area in ORs against high concentrations of BCPs based on good design parameters [41]. However, the performance of VLAF is easily affected by many factors, such as air supply velocity, the obstruction of surgical lamps, the movement of surgical staff, and the thermal plume of the surgical staff [47]. These factors will result in the disruption of laminar flow, forming eddies and reducing the VLAF cleaning efficiency. HLAF is a good alternative to VLAF because it avoids the obstruction of surgical lamps and surgical staff. In HLAF ventilation, the airflow passes through a high-efficiency air filter on the sidewall and then passes through the operating area to achieve air cleaning in the operating area [48].

However, this ventilation system has strict requirements for ventilation design parameters and the layout of the operating room. On the basis of the above mentioned laminar airflow ventilation with a large amount of airflow through the operation area, Differential Vertical Airflow (DVAF) ventilation is used in modern ORs. A DVAF system consists of 25 filters that ensure unidirectional airflow in the operating area. Three central filters above the operating table supply air at the highest airflow velocity, while six filters near them use a moderate airflow velocity. The remaining 16 filters use the lowest airflow velocity [49], experimentally and numerically demonstrated that a DVAF system was effective in reducing the BCP concentration above an operating table based on good design parameters. Moreover, a new OR ventilation system called Temperature-Controlled Airflow (TAF) ventilation was studied [50]. The air supply diffusers were located at the center and surrounding area of the ceiling.

A uniform airflow was sent from the central diffusers, and the temperature was 1.5°C lower than the airflow supplied from the surrounding diffusers [50], compared the differences in BCP concentrations in critical areas of ORs under turbulent mixing airflow, laminar airflow, and TAF at a certain design parameter. It was found that the laminar airflow ventilation and the TAF ventilation systems were able to maintain a clean indoor environment, while the turbulent mixing ventilation system could not. In addition, Wang et al. simulated and compared the above three systems using Computational Fluid Dynamics (CFD) [51]. The results showed that the TAF ventilation system was reliable and effective. Previous studies evaluating the cleanliness efficiency of VLAF, HLAF, DVAF and TAF in ORs with the same simplified supply diffuser conditions have been very limited and not comprehensive. CFD was employed to control the different working conditions and obtained relatively accurate results, which were verified by the corresponding experimental data. In spite of having some advantages, obstructions like surgical lamps and surgical staff, the VLAF system failed to provide a vertical downward laminar airflow. This resulted in a high BCP concentration in the operating area, and this situation was not improved as the airflow rate increased. In the HLAF system, when the airflow rate was greater than a certain value, an ultraclean environment was obtained near the patient and the surfaces of the instrument tables [41]. Once the airflow rate decreased below this value, the air cleanliness deteriorated. When the DVAF system was at a lower airflow rate, the operating area achieved an ultraclean environment. However, the BCP concentration exceeds the recommended limit as the airflow rate increases. Because of the lower BCP concentration in the operating area under different airflow rates, the performance of the TAF system was the best among the four ventilation systems. The results also showed that the BCP concentrations in the operating area under the four ventilation systems were significantly different. In addition, the degree of air cleanliness in the operating area depended not only on the airflow rate of the ventilation system but also on the airflow distribution. The airflow distribution was greatly affected by the surgical lamps and surgical staff. Hence, the position of the surgical lamps should be considered during the design and use of an operating room [41].

Conclusion

SSI is a serious problem in the operation room, which can affect the time of recovery and susceptibility to other disease and as the air borne contamination is the most common source, it is very important to minimize the air contamination. This can be achieved by using laminar airflow and a TAF is supposed to be the best-suited ventilation system that can minimize the airborne contamination.

References

1. He C, Mackay IM, Ramsay K, Liang Z, Kidd T, et al. Particle and bioaerosol characteristics in a paediatric intensive care unit. Environment International. 2017; 107: 89-99.
2. Allegranzi B, Bischoff P, de Jonge S, Kubilay N Z, Zayed B, et al. New WHO recommendations on preoperative measures for surgical site infection prevention: An evidence-based global perspective. Lancet. Infectious Diseases. 2016; 16: e276-e287.
3. Debarge R, Nicolle MC, Pinaroli A, Ait Si Selmi T, et al. Surgical site infection after total knee arthroplasty: a monocenter analysis of 923 first-intention implantations. Rev Chir Orthop Reparatrice Appar Moteur. 2007; 93: 582-587.
4. Kapadia BH, Johnson AJ, Daley JA, Issa K, Mont MA. Pre-admission cutaneous chlorhexidine preparation reduces surgical site infections in total hip arthroplasty. J Arthroplasty. 2013; 28: 490-493.
5. Perennec Olivier M, Jarno P. Surveillance des infections du site opÈratoire en France en 2009-2010. Résultats. Saint-Maurice: Institut de veille sanitaire. 2012.
6. World Alliance for Patient Safety. WHO guidelines for safe surgery. Geneva: World Health Organization. 2008.
7. Weigelt JA, Lipsky BA, Tabak YP, et al. Surgical site infections: Causative pathogens and associated outcomes. Am J Infect Control. 2010; 38: 112-120.
8. Centers for Disease Control and Prevention. National Nosocomial Infections Surveillance (NNIS) System report, data summary from January 1992 through June 2004, Am J Infect Control. 2004; 32: 470-485.
9. Anderson DJ, Kaye KS, Classen D, et al. Strategies to prevent surgical site infections in acute care hospitals. Infect ControlHosp Epidemiol. 2008; 29: S51-S61.
10. Engemann JJ, Carmeli Y, Cosgrove SE, et al. Adverse clinical and economic outcomes attributable to methicillin resistance among patients with Staphylococcus aureus surgical site infection. Clin Infect Dis. 2003; 36: 592-598.
11. McGarry SA, Engemann JJ, Schmader K, et al. Surgical-site infection due to Staphylococcus aureus among elderly patients: mortality, duration of hospitalization, and cost. Infect Control Hosp Epidemiol. 2004; 25: 461-467.
12. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, et al. Surgical site infection: Incidence and impact on hospital utilization and treatment costs. American Journal of Infection Control. 2009; 37: 387-397.
13. Awad SS. Adherence to surgical care improvement project measures and post-operative surgical site infections. Surgical Infections. 2012; 13: 234-237.
14. Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, et al. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. Journal of Hospital Infection. 1983; 4: 111-131.
15. Humbal C, Gautam S, Trivedi U. A review on recent progress in observations, and health effects of bioaerosols. EnvironmentInternational. 2018; 118: 189-193.
16. Hansen D, Krabs C, Benner D, Brauksiepe A, Popp W. Laminar air flow provide high air quality in the operating field even during real operating conditions, but personal protection seems to be necessary in operations with tissue combustion. Int J Hyg Environ Health. 2005; 208: 455-460.
17. Hubble MJ, Weale AE, Perez JV, Bowker KE, MacGowan AP, et al. Clothing in laminar flow operating theatres. J Hosp Infect. 1996; 32: 1-7.
18. Landrin A, Bissery A, Kac G. Monitoring air sampling in operating theatres: can particle counting replace microbiological sampling? J Hosp Infect. 2005; 61: 27-29.
19. Vichard P. L'aérobiocontamination des blocs opératoires: bilan des « sallesblanches ». Rev Chir Orthop Reparatrice Appar Moteur. 2007; 11: 24-25.
20. Merollini KM, Zheng H, Graves N. Most relevant strategies for preventing surgical site infection after total hip arthroplasty: guideline recommendations and expert opinion. Am J Infect Control. 2013; 41: 221-226.
21. Mangram AJ, Horan TC, Pearson ML, et al. Guideline for prevention of surgical site infection 1999. Infect Control Hosp Ep de-

miol. 1999; 20: 247-278.

22. Wenzel RP. Minimizing surgical-site infections. N Engl J Med. 2010; 362: 75-77.

23. Anderson DJ, Sexton DJ, Kanafani ZA, et al. Severe surgical site infection in community hospitals: epidemiology, key procedures, and the changing prevalence of methicillin-resistant Staphylococcus aureus. Infect Control Hosp Epidemiol. 2007; 28: 1047-1053.

24. Howe RA, Monk A, Wootton M, et al. Vancomycin susceptibility within methicillin resistant Staphylococcus aureus lineages. Emerging Infect Dis. 2004; 10: 855-857.

25. Perdelli F, Dallera M, Cristina ML, et al. A new microbiological problem in intensive care units: environmental contamination by MRSA with reduced susceptibility to glycopeptides. Int J Hyg Environ Health. 2008; 211: 213-218.

26. Nichols RL. Preventing surgical site infections: a surgeon's perspective. Emerg Infect Dis. 2001; 7: 220-224.

27. Owens CD, Stoessel K. Surgical site infections: epidemiology, microbiology and prevention. J Hosp Infect. 2008; 70: 3-10.

28. Kirby JP, Mazuski JE. Prevention of surgical site infection. Surg Clin North Am. 2009; 89: 365-89.

29. Wolcott RD, Gontcharova V, Sun Y, et al. Bacterial diversity in surgical site infections: Not just aerobic cocci any more. J Wound Care. 2009; 18: 317-323.

30. Giacometti A, Cirioni O, Schimizzi AM, et al. Epidemiology and microbiology of surgical wound infections. J Clin Microbiol. 2000; 38: 918-922.

31. Spagnolo AM, Ottria G, Amicizia D, Perdelli F, Cristina ML. Operating theatre quality and prevention of surgical site infections. J Prev Med Hyg. 2013; 54: 131-137.

32. Rundstadler Y, Dimajo P. Lutter contre la contamination au bloc operatoire. Paris, France: Elsevier. 2002.

33. Talon D, Schoenleber T, Bertrand X, Vichard P. [Performances of different types of airflow system in operating theatre]. Ann Chir. 2006; 131: 316-321.

34. Pasquarella C, Pitzurra O, Herren T, Poletti L, Savino A. Lack of influence of body exhaust gowns on aerobic bacterial surface counts in a mixed-ventilation operating theatre. A study of 62 hip arthroplasties. J Hosp Infect. 2003; 54: 2-9.

35. Al Akoum M, Duprat S, Lidove A, Rundstadler Y. Modelisation aeraulique de salles d'operation. ITBM. 2004; 25: 107-112.

36. Andersson AE, Bergh I, Karlsson J, Eriksson BI, Nilsson K. Traffic flow in the operating room: an explorative and descriptive study on air quality during orthopedic trauma implant surgery. Am J Infect Control. 2012; 40: 750-755.

37. Knobben BA, van Horn JR, van der Mei HC, Busscher HJ. Evaluation of measures to decrease intra-operative bacterial contamination in orthopaedic implant surgery. J Hosp Infect. 2006; 62: 174-80.

38. Hansen D, Krabs C, Benner D, Brauksiepe A, Popp W. Laminar air flow provides high air quality in the operating field even during real operating conditions, but personal protection seems to be necessary in operations with tissue combustion. Int J Hyg Environ Health. 2005; 208: 455-460.

39. Vichard P. L'aérobiocontamination des bloc's opératoires: bilan des salles blanches. Rev Chir Orthop Reparatrice Appar Moteur. 2007; 11: 24-25.

40. Merollini KM, Zheng H, Graves N. Most relevant strategies for preventing surgical site infection after total hip arthroplasty: Guideline recommendations and expert opinion. Am J Infect Control. 2013; 41: 221-226.

41. Liu Z, Liu H, Yin H, Rong R, Cao G, et al. Prevention of surgical site infection under different ventilation systems in operating room environment. Front Environ Sci Eng. 2021; 15: 36.

42. Gao R, Zhang H, Li A, Wen S, Du W, et al. A new evaluation indicator of air distribution in buildings. Sustainable Cities and Society. 2020; 53: 101836.

43. Stacey A, Humphreys H. A UK historical perspective on operating theatre ventilation. Journal of Hospital Infection. 2002; 52: 77-80.

44. Diab-Elschahawi M, Berger J, Blacky A, Kimberger O, Oguz R, et al. Impact of differentsized laminar air flow versus no laminar air flow on bacterial counts in the operating room during orthopedic surgery. American Journal ofInfection Control. 2011; 39: e25-e29.

45. Hirsch T, Hubert H, Fischer S, Lahmer A, Lehnhardt M, et al. Bacterial burden in the operating room: Impact of airflow systems. American Journal of Infection Control. 2012; 40: e228-e232.

46. Fischer S, Thieves M, Hirsch T, Fischer KD, Hubert H, et al. Reduction of airborne bacterial burden in the OR by installation of unidirectional displacement airflow (UDF) Systems. Medical Science Monitor. 2015; 21: 2367-2374.

47. Cao G, Storås MC, Aganovic A, Stenstad LI, Skogås JG . Do surgeons and surgical facilities disturb the clean air distribution close to a surgical patient in an orthopedic operating room with laminar airflow? American Journal of Infection Control. 2018; 46: 1115-1122.

48. Sadrizadeh S, Holmberg S, Tammelin A. A numerical investigation of vertical and horizontal laminar airflow ventilation in an operating room. Building and Environment. 2014; 82: 517-525.

49. Romano F, Marocco L, Gustén J, Joppolo CM. Numerical and experimental analysis of airborne particles control in an operating theater. Building and Environment. 2015; 89: 369-379.

50. Alsved M, Civilis A, Ekolind P, Tammelin A, Andersson AE, et al. Temperature-controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow. Journal of Hospital Infection. 2018; 98: 181-190.

51. Wang C, Holmberg S, Sadrizadeh S. Numerical study of temperature-controlled airflow in comparison with turbulent mixing and laminar airflow for operating room ventilation. Building and Environment. 2018; 144: 45-56.