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Study on biological contaminant control strategies under different ventilation models in hospital operating room

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Abstract

Transmission of airborne bacteria is the main factor causing surgical site infection (SSI). Previous researches have provided evidence of relationships between cleanness of room air and incidence of SSI, but little work has been done to verify the numerical simulation results of particle dispersion. This paper focuses on the airborne transmission of bacteria in two operating rooms during two surgeries: a surgical stitching of fractured mandible and a joint replacement surgery. Field measurement was carried out in two newly built ISO class 5 (OR.A) and class 6 (OR.B) operating rooms. Bacteria collecting agar dishes were put in different places of the two operating rooms to get the deposited bacteria number during the operation. Then numerical simulation was carried out to calculate the particle trajectories using the Euler–Lagrange approach. Simulation results were compared with field measured data, and acceptable level of consistency was found. Then we changed the supply air velocity and supply vent area in the OR.B numerical model under same room air change rate, to compare bacteria colony deposition onto the "critical area", which consisted of three connected surfaces around the surgical site on patient body. Result showed that improving air flow pattern can reduce particle deposition on critical surface, but its effect is less evident by increasing the air change rate in a certain amount, and we found that bacteria colony deposition would increase (mainly on upper surface), if air velocity increases beyond a certain velocity.

Keywords: Hospital operating room; Particle; CFD; Ventilation

1. Introduction

Based on Centers for Disease Control (CDC) and Prevention National Nosocomial Infections Surveillance (NNIS) system [1] reports, surgical site infection (SSIs) are the third most frequently reported nosocomial infection, accounting for 14–16% of all nosocomial infections among hospitalized patients. In 1980, it was estimated that an SSI increased a patient's hospital stay by approximately 10 days and cost an additional $2000. Advances in infection control practices include improved operating room ventilation, sterilization methods, barriers, surgical technique, and availability of antimicrobial prophylaxis. To reduce the risk of SSI, a systematic but realistic approach must be applied with the awareness that this risk is influenced by characteristics of the patient, operation, personnel, and hospital. Microbial contamination of the surgical site is a necessary precursor of SSI. It is agreed in the literature that the primary sources of such bacteria are squames, or skin scales or particles, and with a dimension of 5–10 μm [2]. These air born coenobiums may deposit on surgical site and cause potential infections.

Since 1960s, when cleanroom technology was applied in operating rooms for the first time, there has been plausible evidence showing good cleanness and well organized airflow pattern in operating room can reduce incidence of SSI. According to Lidwell's [3] statistic analysis result, out of 8025 cases of joint replacement surgeries, when used cleanroom technology only, the SSI incidence dropped from 3.4% to 1.6%; when used antibiotic only, the incidence dropped from 3.4% to 0.8%; when used both cleanroom technology and antibiotic, the incidence dropped to 0.7%. Thus how to improve the performance

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of cleanrooms to more effectively reduce bacteria concentration around surgical site has become an important issue in cleanroom profession.

There is not an international standard for operating cleanroom. The first standard regarding biological cleanroom is carried out by NASA—NASA standard for Clean Rooms and Work Station for Medical Controlled Environment (NHB 5340.2). It sets criterion on concentration of particles and bacteria colonies in different classes of cleanroom. Based on that standard, USA, England, Switzerland and Japan carried out their standard on clean operating room in 1960s. In US, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and The US Department of Health and Human Services carried out similar guidelines, which set criterion on the efficiency of filter in different classes of operating rooms. Japan standard sets criterion on terminal filter efficiency, minimum air change rate and maximum count of bacteria colonies in the operating room. Holland standard VCCN 2001, England standard DHSS (1986), Switzerland standard SKI (1987) and China standard GB50333-2002 specify maximum count of bacteria colonies and set specification on filter and HVAC system. One particular standard is Health Technical Memorandum (HTM) developed by UK National Health Service Estates. HTM 2025 specifies the maximum operational bacteria count, around different areas of the operating room. The required index in this standard is difficult to test and it may potentially induce risk to the patient under operation. But the ultimate goal of all these standards is to control the airborne bacteria colonies around surgical site to reduce chance of infection.

Some works have been done on contaminant dispersion in operating room and indoor environment both experimentally and numerically. Chih-Shan Li et al. [4] carried out a series of field tests with Andersen 1-STG sampler, and got the bacterial and fungal concentrations in different parts of a hospital, including class 100 and class 10,000 clean rooms. Lidwell [5] and Schmidt [6] did lot experiments in operating rooms, comparing bacteria concentration in different air flow patterns. But in their literature, HVAC system's parameter was not included, so their result could not establish definitive recommendation for actual design of HVAC system in operating room.

During-surgery test was sparse, because of consideration on potential risks that would bring to the patient. Currently the during-operation test could only be carried out in surrounding areas of the surgical bed. We could barely know the actual bacteria concentration around the surgical site. A new powerful tool CFD (computation fluid dynamic) has been proved an effective way to investigate air flow and contaminant dispersion in indoor environment. Lot of work has been done on CFD simulation of contaminant dispersion. Farhad et al. [2] simulated air flow pattern and particle trajectories in an operating room with different diffuser types and different range of air change rates. The particle in consideration is 10 μm in size. Three particle source points were analyzed, and tracked. The results showed that ventilation systems that provide laminar flow conditions were the best choice. A face velocity of around 30–35 fpm (0.15–0.18 m/s) was sufficient from the laminar diffuser array, provided that the size of the diffuser array was appropriate. Our investigation here would research into higher supply air velocity, which was filed test velocity in the two rooms. Chen et al. [10] assumed point sources in a room and reported that a higher air inflow rate and a large air inlet area were desirable for contaminant control but detrimental to the thermal comfort of the staff; particle concentrations in various parts of the room were very sensitive to the location of the particle sources. In these work, point source was adopted, this assumption was an inadequate approximation for situations like the one investigated here, in which the bacteria emission model was based on experimental tested data of operating staff, which will be described in detail later. Chow et al. [11] assumed a bacteria emission rate of 100 CFU/min for each operating staff in a non-standard operating room, with a supply diffuser screened with a perforated steel plate. Field test data was set as the boundary condition of supply velocity profile under the diffuser. Simulation was done on temperature distribution, air flow pattern and the contaminant dispersion. Results showed that bacteria concentration was very sensitive to the position of lamps. In their simulation field tested supply velocity profile enhanced their result's reliability, but they did not testify their particle transport simulation result, and the operation room in their work was a non-standard operation room, which limited its utilization in modern operation rooms. Woloszyn et al. [12] compared experimentally measured tracer-gas concentration and simulation result in an operating room with a diagonal air-distribution system. Tracer-gas method has been a very handy method to observe contaminant dispersion in a space, but as we all know the particle's dispersion characteristic was not the same with gases, so the tracer gas method cannot represent so well the airborne bacteria diffusion in an operating room. Our investigation here uses the Lagrangian formulation to calculate the trajectories of particle, and finds a way to testify the deposited bacteria number. Woods et al. [13] developed a two-compartment model in cleanroom air. They divided the room into two parts, one was "micro-environment" and was defined as the space bounded by the patient, the surgical team around the operating table, and the surgical lamps above the patient; the other was "mini-environment", which was the space within the operating room and enveloped the micro-environment. The idea of dividing operating room into two parts was constructive, but the "mini-environment" may be too large, we defined a "critical area", which consisted of three connected area around the surgical site on patient body. We calculated the number of bacteria deposited on these three surfaces. After all, the surgical site bacteria concentration was crucial to the rate of SSI. This body of work is important and has improved some contamination control technologies in