NUMERICAL STUDY ON EFFECT OF OPERATING TABLE PROTECTED BY HORIZONTAL LAMINAR FLOW SCREEN

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Abstract: Transmission of airborne bacteria is the main factor causing surgical site infection (SSI), which is harmful to patients' health and even lives. Numerical study is conducted on the effect of the operating table protected by horizontal laminar flow screen. Discrete phase model (DPM) is used. Numerical simulation is carried out to evaluate particle trajectories with the Lagrange approach. As a result, the protecting effect of horizontal laminar flow screen is established, and the protecting parameters of the air velocity supplied by the screen and the protecting distance are optimized. The optimized air velocity supplied by the screen should be at 0. 4—0. 6 m/s. And the protecting distance should be less than 1. 3 m. This work provides references for the study on the depuration of operating table or room.

Key words: laminar flow screen; particle trajectories; discrete phase model; operating table

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INTRODUCTION

Transmission of airborne bacteria is the main factor causing surgical site infection (SSI), which is harmful to patients' health and even lives[1-2]. Microorganism in the air is mainly produced by persons, walls and ground. Controlling surgical site infection and disinfecting all of the things which are directly or indirectly contacted with patients have already become a recognized standard. After disinfection, the count of the attached bacteria can be considered to be zero. Therefore, the most important source of bacteria and dust is the human body itself in the operating room[3-4]. Many studies have shown that bacteria in the operating room are mainly carried by the shed skin scrapings so that the operative incision has contained microorganism. In order to prevent infection caused by surgical operation, air purification measurements of operating room environment are the most significant means[5-7].

Compared with the high consumption operating rooms with overall laminar flow ventilation, the use of the local laminar airflow unit may be an inevitable trend of development[8]. Research on the air-flow organization and pollutant concentration in operating room has experienced three stages as follows: First, the follow-up survey of infection rate was focused on; then, the bacterial concentration under different air distribution ways was studied experimentally; and nowadays, numerical simulations of bacterial concentration under different air distribution ways have been studied[9-10]. Many researches focused on the comparison of the means of airflow which included horizontal and vertical laminar airflow[11-12]. The results showed that the vertical laminar airflow

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purification technology improved the whole room's cleanliness, but had little effect on local pollution in the operating areas; while the horizontal laminar airflow could help to push away the microbial aerosol from operating table so as to achieve better local purification. Some researches also focused on the horizontal laminar airflow, but most of them aimed at the whole operating room of horizontal laminar airflow, few of them aimed at local key areas. The construction of a whole operating room of horizontal laminar airflow costs more, while the effect of purification at the key area of operation is not better than the effect with local purification instruments of horizontal laminar flow screen.

In this paper, for local purification of operating room, numerical study is conducted on the effect of the operating table protected by horizontal laminar flow screen. And the optimal conductions of the protection on key area of the operation by horizontal laminar flow screen are obtained.

1 SIMULATION METHOD

Computational fluid dynamics (CFD) methods[10] and discrete phase model (DPM) are used in this work. Two-dimensional model for the flow field is established based on the physical model of air jet provided by horizontal laminar flow screen. The model is shown as Fig. 1, the height of the screen which provides clean air is 0.6 m, the length of the jet trajectory from the screen is considered as 1 m or 2 m, and the area from point 1 to point 2 is defined as the key area of operation, the length is 0.5 m. Suppose that the pollutant particles come from the upside of the area. Standard k-epsilon two-equation is used to simulate the jet. In the turbulence model, k means the turbulent kinetic energy and ε means the dissipation rate[13]. This equation assumes that the flow field is completely turbulent, and viscosity between molecules can be ignored. Gravity would be considered. Stochastic trajectory model is adopted to simulate the particle trajectory of the contamination. Lagrangian approach is used to simulate the particle trajectory in the jet[14]. In DPM, different boundaries have different reactions to the particles: Inlet is set as reflect, key area of operation is set as trap, outlet is set as escape, and other boundaries are set as reflect. Boundary conditions of this mode are set as follows: The type of inlet is set as velocity-inlet; the type of the key area is set as wall; the type of outlet is set as outflow; the type of particle source is set as mass-flow-inlet; the types of other boundaries are set as wall. The temperature is set as 300 K. The mesh is generated by software of Gambit, shown as Fig. 2. The count of the particles of contamination at the key area of operation is calculated, in order to evaluate the effect of the operating table protected by horizontal laminar flow screen [15]. When the length of the jet trajectory from the screen is considered as 1 m, the particle trajectories of the contamination are simulated at different initial air velocities (0.6, 0.4, 0.2, 0 m/s) from the inlet. And then, the length of the jet trajectory from the screen is considered as 2 m to optimize the protecting distance of the screen.

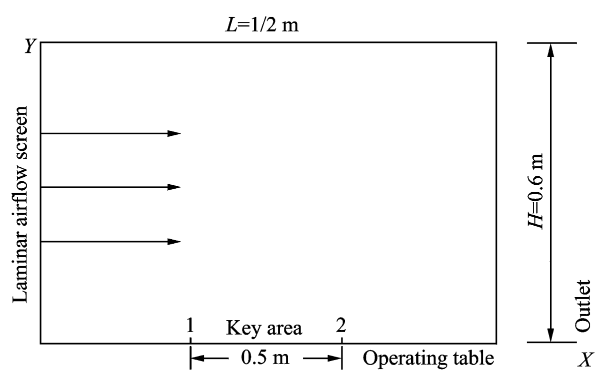


Fig. 1 Sketch of model for flow field

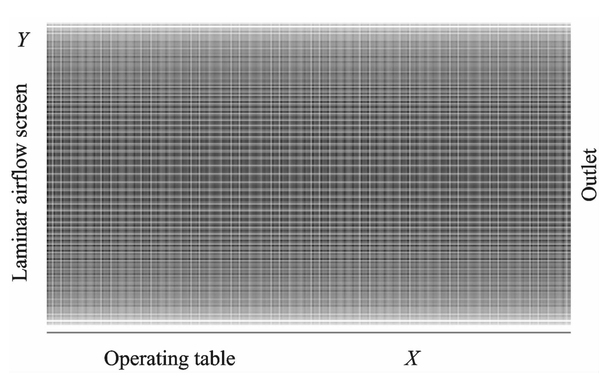


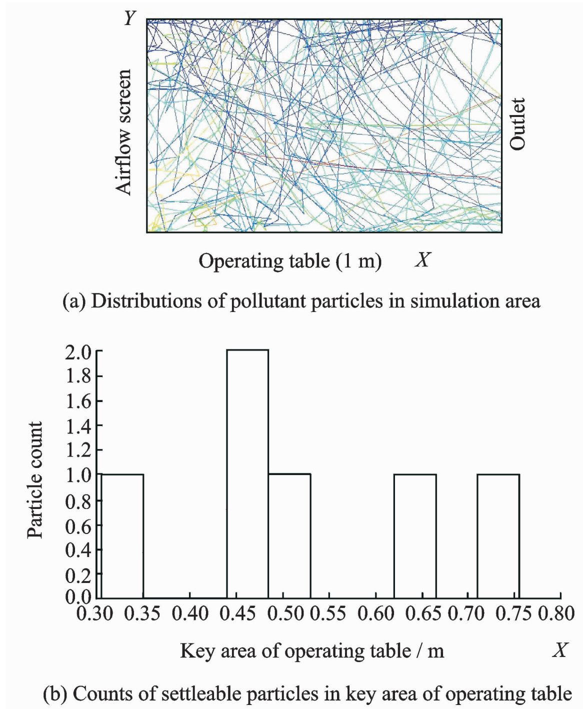
Fig. 2 Sketch of mesh

2 EXPERIMENTAL RESULTS

2.1 Effect of initial air velocity provided by screen

The length of the jet trajectory from the screen is considered as 1 m, and simulations are conducted at different initial air velocities. According to the National Standard (GB 50333—2002): Architectural Technical Code for Hospital Clean Operating Department, the initial air velocity of indoor cycle should be no more than 2 m/s[16]. And assuring that the new or return air velocities in the operating room would not be influenced, and the initial air velocity should be as small as possible. When the initial air velocities are set as 0, 0.2, 0.4, 0.6 m/s, the simulation results of the particle trajectories of the contamination are shown as Figs. 3—6. Figs. 3(a),4(a), 5(a),6(a) show the distributions of the pollutant particles with different initial air velocities, where the colored lines represent the particle trajectories of the contamination. Figs. 3(b),4(b),5(b),6(b) show the distribution probabilities of particles at outlet boundary with different initial air velocities. Particularly, Fig. 3(b) shows the counts of particles depositing at the key areas of operating table with the initial air velocity at 0 m/s.

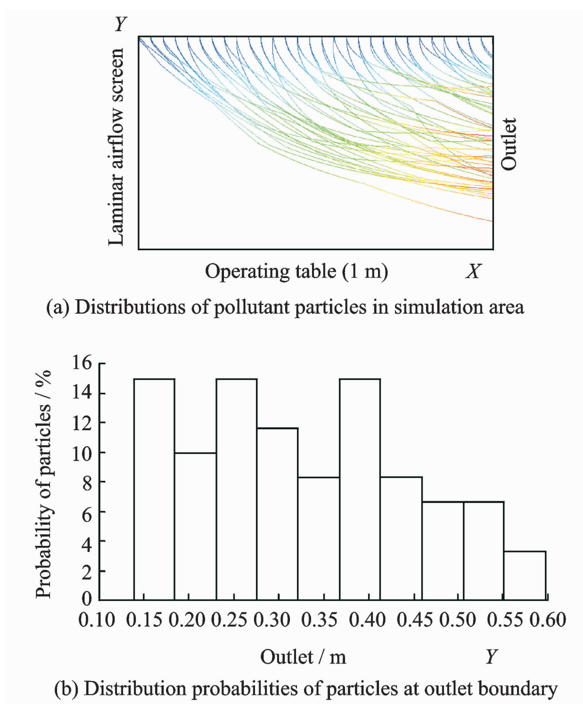
As Fig. 3(a) shown, the particle trajectories of the contamination are disorderly, and as Fig. 3 (b) shown, the particles of contamination are deposited at the key area of operating table without the work of horizontal laminar air flow. While as Figs. 4—6 shown, the particle trajectories of the contamination are well-regulated, and most particles move at the X-direction velocity. When the particles of the contamination are deposited in the key area of operating table, these particles are "trapped". As a result, the numbers of the tracked and escaped particles are 60, and the numbers of aborted, trapped, evaporated, and incomplete ones are 0, with the initial air velocities at 0.2, 0.4 and 0.6 m/s. While the number of the tracked, escaped and trapped particles respectively is 60, 53, 7, and the numbers of aborted, evaporated and incomplete ones are 0, with the



(a) Distributions of pollutant particles in simulation area

(b) Counts of settleable particles in key area of operating table

Fig. 3 Particle trajectories of contamination (v=0 m/s)



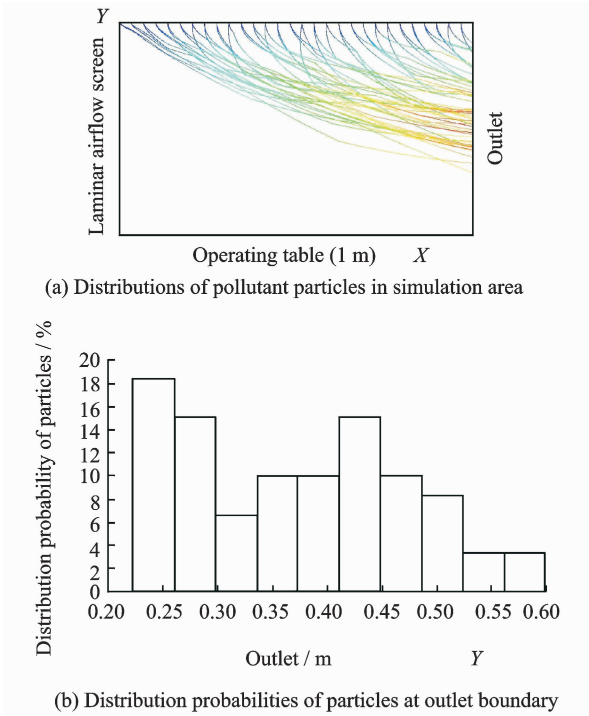
(a) Distributions of pollutant particles in simulation area

(b) Distribution probabilities of particles at outlet boundary

Fig. 4 Particle trajectories of contamination (v=0.2 m/s)

initial air velocities at 0 m/s. This means the horizontal laminar flow screen is effective to avoid contamination.

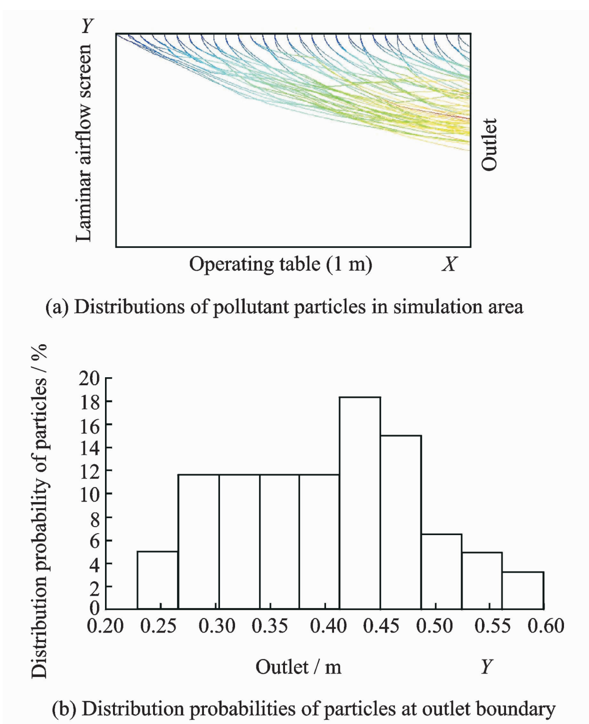
As Fig. 4(b) shown, the particle trajectories are intersected 45.5% with the outflow boundary



(a) Distributions of pollutant particles in simulation area

(b) Distribution probabilities of particles at outlet boundary

Fig. 5 Particle trajectories of contamination (v=0.4 m/s)



(a) Distributions of pollutant particles in simulation area

(b) Distribution probabilities of particles at outlet boundary

Fig. 6 Particle trajectories of contamination (v=0.6 m/s)

(Y<0.3 m, close to the operating table). As Fig. 5(b) shown, the particle trajectories are intersected 33.5% with the outflow boundary (Y<0.3 m). As Fig. 6(b) shown, the particle trajectories are intersected 17% with the outflow boundary (Y<0.3 m). The smaller the percent is, the safer the operating table is. Therefore as Figs. 4—6 shown, the particle trajectories of the contamination are affected by the initial air velocities, that is, 0.6 m/s is better than 0.4 m/s, and rather better than 0.2 m/s. However, to be comfortable in operating room, the air velocity should not be too large, so the optimal velocities are chosen at 0.4—0.6 m/s.

2.2 Effect of protecting distance

The length of the jet trajectory from the screen is considered as 2 m. According to the analysis above, the velocities are chosen at 0.4—0.6 m/s, so the initial air velocity is chosen at 0.5 m/s, and the particle trajectories of the contamination are shown as Fig. 7, where colored lines represent the particle trajectories of the contamination.

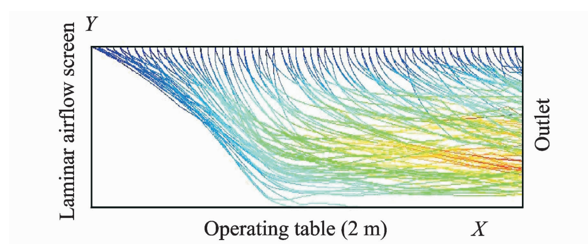


Fig. 7 Particle trajectories of contamination (v=0.5 m/s, simulation length=2 m)

As a result, when the key area of operating table is set farther than 1.3 m from the protecting screen, the simulation results are as follows: The number of the tracked, escaped, aborted, trapped, evaporated, and incomplete particles respectively is 113, 120, 0, 17, 0, 0, and 15% particles are trapped. Therefore, in this action, the protecting distance of the laminar airflow screen should be less than 1.3 m.

3 CONCLUSIONS

Numerical study is conducted on the effect of the operating table, especially the key area, protected by horizontal laminar flow screen in this paper. CFD method is used and numerical simulation is carried out to evaluate particle trajectories with the Lagrange approach. Suppose other factors, for example, the movements of health care workers or equipments in the operating room, can not influence the protecting effect of the horizontal laminar flow screen. As a result, the local protecting effect of horizontal laminar flow screen is established, and the protecting parameters are optimized as follows:

(1) When the distance between the screen and key area is less than 1.3 m, the air velocity supplied by the screen should be at 0.4—0.6 m/s, which is reliable and according with the criterion of the operating room.

(2) When the air velocity supplied by the screen is at 0.5 m/s, the protecting distance of the laminar airflow screen should be less than 1.3 m.

This protection is aimed at the key area of operating table, so this work will provide references for the study on the local depuration of operating table or room.

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