The problem of surgical wound infections: air flow simulation in operating room

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1. Introduction: surgical wound infection

The present study deals with the management of the clinical risk, defined as “the probability that a patient undergoes an adverse event, i.e. damage, also unintentional, caused by the medical treatment during the hospitalization that causes a worsening of the health condition of the patient or his death”. The clinical risk can be limited in a hospital by the institution of Clinical Risk System and above all, of a Medical Engineering Service, that assure the efficient and economical use of a medical device, producing more tightly procedures also in the starting test of a device. Every year in Italy almost 10% of the hospital-patients is affected by an infection, with an increase of the costs for the National Health Service. Specifically, surgical infections are 10-30% of the total nosocomial infections. The main microrganisms causing the surgical infections are Stafilococcus Aureus, Pseudonomas and Escherichia Coli. When these particles join the “right” target they can make a colony, causing an infection of the surgical wound [8]. Beside the state of the patient, it is present also an increase of costs for the National Health System. A typology of surgical activities where the infection can be very serious is the implant of haunch or knee arthroprosthesis [2], [4], when an infection can even lead to the mobilization of the prosthesis.

2. Aim of the study

Despite the precautions realized in operating room, surgeons and other clinical operators emit physiological particles fluctuating in the air overlying the operating table, thus producing a potential risk for the patient. As far as the causes of the infections in operating room is concerned, a Fluid-Dynamics model has been used with the aim of studing air flows inside the operating room and evaluating the probability of an occurring infection of surgical wound. The geometrical model of a real operating room has been built using the software Gambit, and the Fluid-Dynamics simulations have been carried out with Fluent. The reviewing of the numerical simulations allowed to make proposals in order to minimize the contamination of the air near the patient surgical wound.

3. Operating Room

The official definition of the operating room is a medical local of Group 2, i.e. following the norm CEI 64-8/7, “a medical local where the parts applied to the patient are finalized to be used in cardiac operations or where patient undergoes vital treatment and loss of energy can cause a life danger”.

A standard operating room is characterized by an extreme technological complexity, where are present many electromedicals, as operating table, sciatic lamps, anesthesia devices, electrosurgical devices, defibrillators, etc. In operating rooms air is required to have suitable characteristics to preserve optimal conditions for well-being of the medical staff and of the patients which undergo surgical operations. It is then necessary to be careful about Colony Forming Unit (CFU) floating in air.
If these particles join the “right” target, they can make a colony causing an infection of the surgical wound. Once this control is realized, climatization system is defined a “Controlled Air - Contamination System” [5], [6], [3], [7].

4. Operating Room Modeling

The core of the present study is to use a Fluid-Dynamics model with the aim of studying air flow inside the operating room. Computational Fluid-Dynamics can simulate the velocity field of a fluid crossing a surface of every shape, under established boundary conditions.

The first part of the work is modelling an Operating Room using the software Gambit. The real operating room is that existing at the Policlinico Tor Vergata of Rome (N.5 of the next opening Operating Zone), with a laminar diffusion of air from the top of the room. The real dimensions of the OR are used, integrated with data obtained by in situ inspection.

In the analysis of the chosen OR the grids of air recirculation are considered and the air-laminar diffusion from the ceiling of the room. The main purpose of this study is to determine the air velocity inside the OR during a normal activity, i.e. when several equipments are influencing the flow. It is then necessary to investigate every part of OR, considered important for the Fluid-Dynamics simulation. The two main important devices to investigate are the real Maquet operating table and the real Martin Scialitic lamps. In order to obtain important information about the problem of sterility in OR, the complete OR with the operating table, the patient, the scialitic lamps and the health operators are investigated in different configurations.

The following step is the creation of the mesh which can discretize the built volumes.

In the first configuration the OR without any items inside is analyzed, while in the B configuration the operating table with the patient and 2 surgeons are considered. Because the target is to study in detail the trend of the sterile air flow near the surgical wound, which can potentially affect with an infection, a denser mesh is put in the interested zones. Specifically, a mesh with a step of 20 mm has been put along the surface delimiting the patient body.

In the C configuration is present the operating table with the patient and the scialitic lamps, while in the last D configuration the complete OR is considered, i.e. with the patient, the operating table, the scialitic lamps and the surgeons.

The Boundary Conditions for the single faces of the total volume are necessary.
5. Simulations

The simulation can be carried out with the software Fluent with the meshing volumes made by Gambit, after optimization of the shapes of the tetraedrons of the mesh, confirmation of the b.c. and the verification of the convergence criteria. Next figures show several simulations made with different b.c. Figures 5-6 are relative to the simulations in the OR without patient and surgeons.

Next figures are relative to air velocity field on two special planes. Plane 1 is an XZ plane passing on the knee of the patient while plane 2 is a YZ plane passing through the patient. Figure 7 is concerning the air velocity profile on plane 1, and Figure 8 on plane 2. Figure 9 presents the turbulence viscosity of air inside the OR.

The last two cases show a good laminar diffusion of air between the ceiling of the room and the operating table zone, also without air turbulence near the patient. The main reason is the absence of obstacle in this area. It can be verified the b.c. stated in the simulation. This is the ideal case for the patient, because the sterile air flow is close to the surgical wound, and the probability of an infection is very small.

The next configurations, more realistic, show different results of the simulation. The C configuration is presented in Figures 10-12 representing the complete OR with the operating table, the patient, the lamps, and 4 surgeons.
Air velocity profile on plane 1 and 2 and turbulence viscosity on plane 2 are very complex and irregular due to the many items present in this configuration. Air flow near the patient is not laminar. In this configuration are also present surgeons who contribute to the non laminar behaviour of air flow near the operating table. Figure 12 show high values of air turbulence below the lamps, which are very important in the present simulation. Eddies of air are maximum just close to the surgical site, which is the worst case for the infection probability. In this case air is stagnant and laminar sterile air flow does not reach the wound, with a greater probability that a potentially infective particle could reach the surgical wound.

6. Simulations by using a thicker mesh

A new mesh with a step of 100 mm for the OR space and 20 mm for the patient surface and the recirculation air grid has been used and the results are shown in Fig.13.

The residuals of the several computed parameters show a regular trend.

Figures 14 and 15 show air velocity vectors and turbulence viscosity on plane 2 with an evident higher level of spatial resolution of the simulations.

7. Assessment of using an additional sterile laminar air flow

It is here proposed to use a solution to optimize the laminar flow in the zone near the surgical wound, by introducing inside the OR one more device, i.e. Toul Maquet, which is already existing in the market. The proposed device can produce another laminar flow moving toward the patient with a velocity of 0.4 m/s, after a HEPA filter, [1]. This filter can make cleaner the air near the wound, inducing a lower probability of infection.

The final part of the present paper presents simulations carried out in presence of the HEPA filter according to the configuration presented in Fig. 16. Simulations are done similarly to the previous approach for all the OR configurations. The boundary condition used with this filter is relative to the surface in front of the surgical wound of the patient, i.e. knee in the present paper. From this surface is coming a sterile air with velocity 0.4 m/s and 295 °K temperature. The other boundary conditions of the OR are the same.

Results of the simulations are presented in Figures 17-18-19, showing that air velocity vectors are more parallel than in absence of the new device, which produces additional laminar air flow toward the surgical wound. Air velocity near the wound is close to 0.4 m/s, which implies a lower degree of air stagnation and a lower probability of infective event. Figures 17, 18 and 19 show a decrease of
turbulence viscosity near the surgical wound in presence of the additional sterile air flow.

Fig.17 - air velocity vectors on plane 2 (m/s) in a complete OR with an additional sterile laminar air flow

Fig.18 - air velocity vectors on plane 2 (m/s) in a complete OR with an additional sterile laminar air flow: magnification

Fig.19 - air turbulence viscosity (Kg/m-s) on plane 2 without the additional sterile laminar air flow (a) and with it (b).

8. Conclusions

A Fluid-Dynamics model has been used to study air flow inside a real Operating Room of the Policlinico Tor Vergata of Rome. The laminar diffusion of air from the top of the room has been investigated in different configurations, i.e. in presence of a complete operating room, e.g. with the operating table, the patient, the scialitic lamps and the health operators. The simulations on the OR with the operating table, the patient and without the lamps, have shown that the air laminar diffusion on the top of OR produces a privileged space without turbulence, maximizing the air cleanness near the surgical site. The situation changes dramatically when the OR is complete, i.e. including the scialitic lamps overlying the patient. It has been observed the presence of eddies, especially near surgical wound. Similar conclusions can be made analyzing the parameters directly related to the turbulence of the air flows, which show a turbulence activity above the scialitic lamps. Then, air stagnation around the surgical wound is increased and the potentially infective particles may easily cause an infection.

In order to find a solution to the problem of infective events, the complete operating room has been investigated with the presence of a device able to produce additional sterile air flow. The resulting simulations show that air flow vectors near the surgical wound are more regular and less turbulent than without it. A lower air stagnation around the surgical wound has a smaller probability of an infective event.

References