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Wound ventilation with carbon dioxide: a simple method to prevent direct airborne contamination during cardiac surgery?

M. Persson[a,b,*], J. van der Linden[a*]

[a]*Department of Cardiothoracic Surgery and Anesthesiology, M85, Huddinge University Hospital, Karolinska Institute, SE-141 86 Stockholm, Sweden*
[b]*Division of Medical Engineering, Department of Laboratory Medicine, Huddinge University Hospital, Karolinska Institute, SE-141 86 Stockholm, Sweden*

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Summary Carbon dioxide (CO_2) insufflation in the cardiothoracic wound cavity is used in open-heart surgery for prevention of arterial air embolism. The objective of this study was to investigate if CO_2 insufflation may influence the rate of airborne contamination of the cardiothoracic wound. This was studied in a cardiothoracic wound cavity model that contained two 9 cm blood agar plates. Contamination rates were compared between a control without insufflation and insufflation with: (1) a thin open-ended tube or a gas-diffuser, (2) air or CO_2, and (3) CO_2 flows of 5 or 10 L/min. CO_2 insufflation at 5 L/min with an open-ended tube resulted in a contamination rate almost four times that of the control ($P = 0.01$), whereas with the gas-diffuser the contamination rate decreased ($P = 0.01$). With the gas-diffuser, air insufflation at 5 L/min markedly reduced the contamination rate compared with the control ($P < 0.001$), but was less protective than CO_2 insufflation at the same flow ($P < 0.001$). With both gases, the contamination rate was particularly low close to the gas-diffuser ($P < 0.001$). Increasing the CO_2 flow from 5 to 10 L/min reduced the average contamination rate in the model from 30% to 22% ($P < 0.001$) of the control. At a CO_2 flow of 10 L/min the contamination rate within 9 cm of the gas-diffuser was 14% of the control. Intraoperative wound ventilation with CO_2 using a gas-diffuser may not only prevent air embolism, but may also significantly reduce the risk of airborne contamination and postoperative wound infection in cardiac surgery. In contrast, insufflation with an open-ended tube substantially increases these risks.

*Corresponding authors. Address: Department of Cardiothoracic Surgery and Anesthesiology, Huddinge University Hospital, M85, SE-141 86 Stockholm, Sweden. Tel.: +46-8-585-862-96; fax: +46-8-585-867-40.
E-mail addresses: m.persson@labmed.ki.se, jan.vanderlinden@thsurg.hs.sll.se.

Introduction

The incidence of deep wound infections after cardiac surgery usually ranges between 1% and 2%,

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and this complication is associated with a high mortality, ranging between 10% and 40%.[1-4] Most often the agent responsible for cardiothoracic wound infections is *Staphylococcus aureus*,[1,2,5,6] which forms part of the skin flora and spreads into the environment with the shedding of loosely attached squamous cells.[7] The cleaned and draped patient is not considered a source of airborne contamination.[8] However, any other active person present in the operating room may contribute since we all emit thousands of bacteria-carrying particles every minute.[9-11] Squamous cells that have been shed may contaminate the surgical wound during cardiac surgery, despite conventional operating theatre ventilation.[12,13] Ironically, the use of laminar ultra-clean airflow from the ceiling downwards to the operating table may help to convey airborne particles from the surgical team into the operating field. It has been reported that when the surgeon leans over the wound in such an airflow direct airborne wound contamination increases 27-fold.[14] Thus, the question arises whether the ventilation flow should be directed the other way around and emanate from the wound itself.

During the last 50 years, cardiac surgeons have used insufflation of carbon dioxide gas (CO_2) in the cardiothoracic wound cavity as a method of preventing cerebral and myocardial air embolism during open-heart surgery.[15] However, the potential influence of CO_2 insufflation on airborne contamination has never been considered. The commonly used insufflation device is a thin conventional open-ended tube. As its efficiency has recently been questioned,[16,17] we have developed a new insufflation device, a gas-diffuser.[18,19] The objective of this study was to investigate how gas insufflation with these devices affects the rate of airborne contamination in a cardiothoracic wound cavity model.

Methods

Instrumentation

Medical CO_2 or clean laboratory air was used for insufflation into a wound cavity model as described below. The gas flows were controlled by calibrated back-pressure compensated flowmeters.[18]

Insufflation devices

The new gas-diffuser (Cardia Innovation AB, Stockholm, Sweden) is a disposable device that consists of a 1/4 inch gas line with a 0.2 μm bacterial filter, and a distal 2.5 mm tube with a diffuser at the end. The open-ended tube, with an inner diameter of 2.5 mm, was made by cutting away the diffuser of the gas-diffuser device. Thus, both insufflation devices included a 0.2 μm bacterial filter, and the insufflated gas could therefore not contaminate the wound model.

Study protocol

The study was carried out in a part of our departmental facilities where there were people in activity. Airborne bacteria were sampled in a model of a cardiothoracic wound cavity (Figure 1) containing two standard 9 cm blood agar plates. In order to obtain reliable estimates of the contamination rates, the measures of the model were based on the maximal measurements of the open wound cavity of adult patients undergoing cardiac surgery.[18] The model was elliptical with a length, width, and depth of 20, 12, and 8 cm, respectively. Three wound models were positioned 20 cm apart on a 60 × 100 cm tabletop (Figure 2), which was kept 20 cm above the floor. This permitted sampling of particles with a wide size range, while avoiding heavy non-airborne particles. A hollow metal framework surrounded the table in order to keep people away from the wound models. Before sampling, the tabletop, framework, and models were cleaned with alcohol. Six blood agar plates marked with letters A to F were then positioned in the models as shown in Figure 2. A sterile insufflation device was positioned at the acute end of two of the three models. The orifice of each device was located inside the cavity approximately 2 cm from the brim. The open-ended tube pointed towards the centre of the model, which has been our, and others',[20,21] usual clinical position to achieve a central supply of CO_2 (Figure 1), whereas the

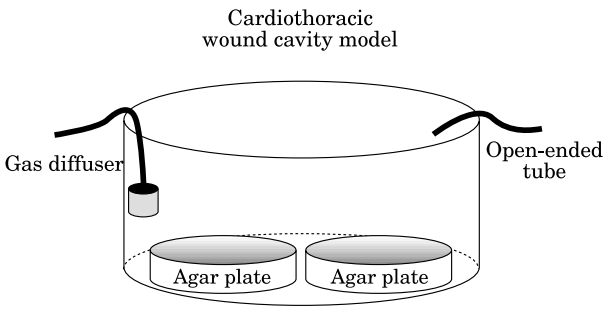

Figure 1 A cardiothoracic wound cavity model with an elliptic shape and a length, width, and depth of 20, 12, and 8 cm, respectively. Two standard 9 cm blood agar plates were positioned at the bottom of the model for assessment of direct airborne contamination. The figure also shows how each insufflation device was positioned in the model during the experiments.

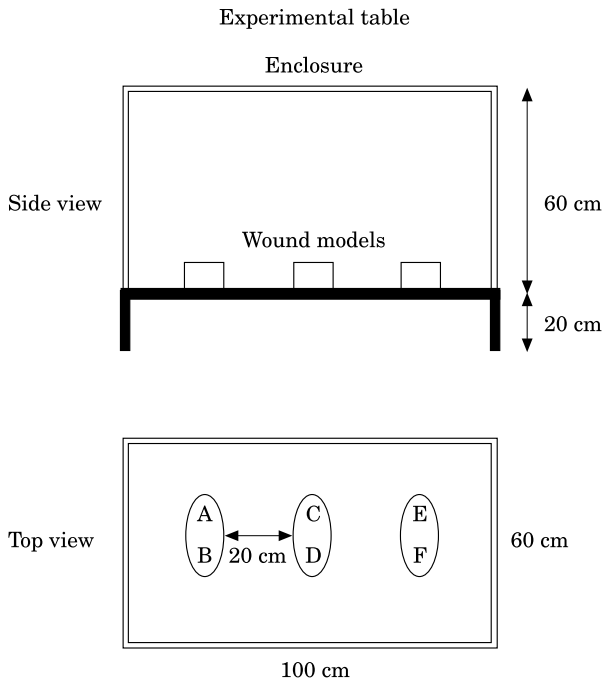

Figure 2 Positions of the three cardiothoracic wound cavity models, containing agar plates at positions A to F. Gas was not insufflated in one of the three models which acted as a control. The wound models were positioned 20 cm above the floor on a disinfected table-top that was surrounded by a hollow enclosure.

gas-diffuser, which produces a multidirectional gas flow, was positioned at half the depth of the cavity pointing downwards. We have found this position suitable for efficient de-airing of the cardiothoracic wound.[22]

The study was divided into three experiments, each including two competing models with insufflation, and one control model without insufflation.

Experiment I (open-ended tube versus gas-diffuser): first, the rate of airborne contamination was studied when CO_2 was insufflated at 5 L/min with an open-ended 2.5 mm tube and a gas-diffuser. In this experiment, which was repeated eight times, the control wound model was positioned in the middle (C and D), whereas the insufflation devices were randomized to position A, B and E, F.

Experiment II (air versus CO_2): second, the contamination rate was studied when air and CO_2, respectively, were insufflated at 5 L/min with the gas-diffuser. In experiments II and III the gas-diffusers were randomized to all positions (A to F), including the position of the control model, giving altogether 24 measurements in each experiment.

Experiment III (5 versus 10 L/min): third, the contamination rate was studied with the gas-diffuser at CO_2 flows of 5 and 10 L/min, respectively.

In each experiment the gas was allowed to flow during 2 min before the agar plates were opened with the help of a disinfected device, consisting of a metal rod with a suction-disk at its distal end. The covers of the agar plates were placed on a disinfected surface. After 3 h of sampling the agar plates were closed inside the models while the gas was still flowing. The agar plates were then incubated at 37 °C for 48 h, whereupon a laboratory technician, blinded as to the position of the plates, counted the number of bacterial colonies.

Statistical methods

In each experiment we compared the number of colonies on the plates in the insufflated wound models with the average number of colonies in the control model. We also compared the number of colonies between the proximal and distal plates within the same insufflated wound model. The non-parametric Mann–Whitney U-test or the Wilcoxon test for paired samples were used for $N = 8$, and the paired t-test was used for $N = 24$. A P-value of <0.05 was considered statistically significant. Data from experiment I, with $N = 8$, are presented as medians with ranges. Data from experiments II and III, each with $N = 24$, are presented as means with standard deviations.

Results

Experiment I

With the open-ended tube the number of colonies was much higher on the agar plate distal to the tube than on the proximal plate [$P = 0.01$, Figure 3(a)]. In contrast, with the gas-diffuser there was no statistical difference in number of colonies between the distal and proximal agar plate ($P = 0.17$). In comparison with the control (100%) without insufflation, the number of colonies was higher ($P = 0.01$) with the open-ended tube on the distal plate (383%). However, there was no statistical difference between the control and proximal plate (125%, $P = 0.18$). With the gas-diffuser the number of colonies was lower ($P = 0.01$) on both the proximal (24%) and distal agar plates (43%), in comparison with the control.

Experiments II and III

With air as well as with CO_2 there were fewer colonies on both agar plates in the model, in comparison with the control [$P < 0.001$, Figure 3(b)]. Moreover, with both gases the number of colonies

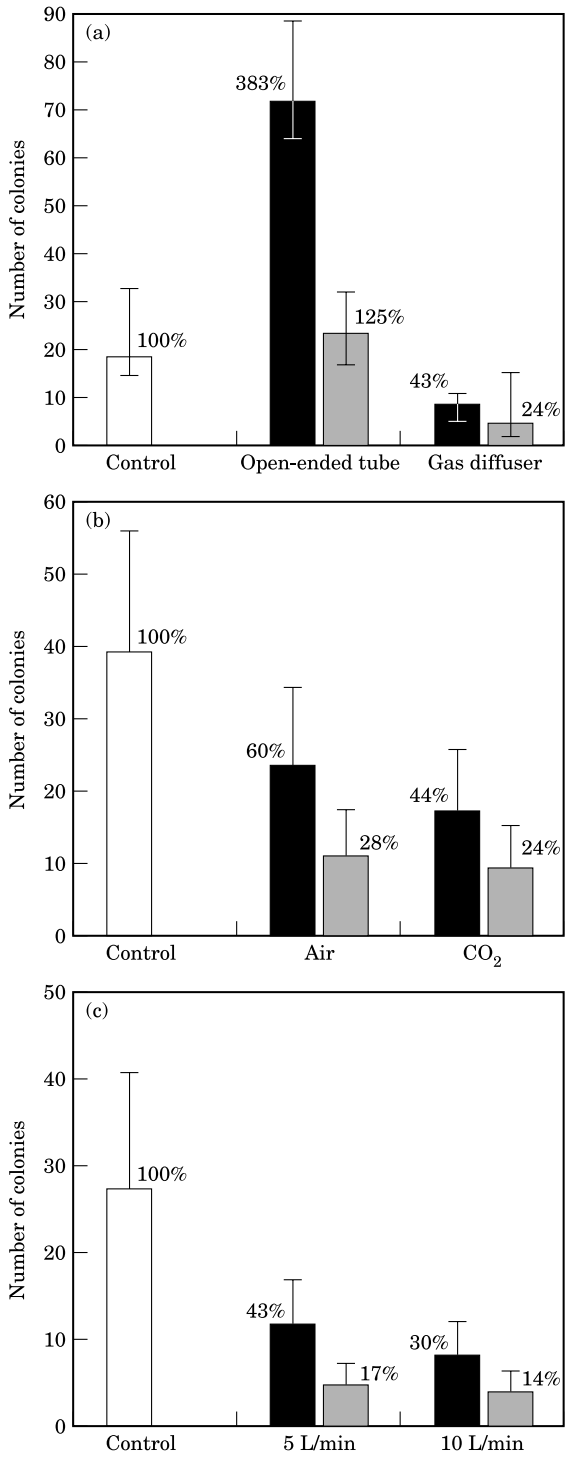

Figure 3 Number of bacterial colonies on the agar plate distal and proximal to the insufflation device in the wound model. The model was insufflated with (a) a CO_2 flow of 5 L/min using an open-ended tube or a gas-diffuser, (b) air or CO_2 at 5 L/min with a gas-diffuser, and (c) CO_2 at 5 or 10 L/min with gas-diffuser. Values in (a) are presented as medians with ranges ($N = 8$), and means with SD ($N = 24$) in (b) and (c), and as the percentage of the control (100%). (■) Distal agar plate; (■) proximal agar plate; (□) average of the two control plates.

was lower on the agar plate proximal to the gas-diffuser than on the distal plate ($P < 0.001$). Insufflation with CO_2 resulted in fewer colonies than with air insufflation ($P < 0.001$), both on the proximal (24%, 28%) and the distal plate (44%, 60%). On the distal plate a CO_2 flow of 10 L/min resulted in a lower number of colonies than with 5 L/min [30%, 43%, $P < 0.001$, Figure 3(c)], but on the proximal plate there was no statistical difference in number of colonies between 10 and 5 L/min (14%, 17%, $P = 0.20$).

Discussion

Direct airborne contamination of the surgical wound increases the risk of postoperative wound infection. Friberg *et al.*[23] found a strong correlation between the air count and the surface count of bacteria-carrying particles, while Lidwell *et al.*[24] found the air count of bacteria near the wound to correlate with the infection rate in joint replacement operations. Conventional cardiac surgery is similarly exposed to airborne infection as it also involves the introduction of foreign material in the form of prosthetic devices and metal wires for fixation of the sternum. The use of internal thoracic artery grafts in coronary bypass surgery reduces the perfusion of the sternum,[25] and is an important risk factor for postoperative deep wound infection.[3] Furthermore, many cardiac patients may have pre-existing impaired tissue perfusion due to atherosclerosis or cardiac failure. Combating airborne infection therefore should be regarded as a matter of high priority in cardiac surgery. A case could even be made that direct airborne contamination is more important in cardiac than in orthopaedic surgery as in cardiac surgery the wound area that faces upwards is usually larger,[26] also operations usually last for several hours. Thus, preventing airborne particles from reaching the cardiothoracic wound may be of benefit.

When considering the role that wound ventilation might play in combating airborne infection, it should be kept in mind that when CO_2, which is 50% heavier than air, is continuously supplied to a wound cavity, surplus CO_2 gas will overflow out of it. This continuous overflow from the wound may transport particles away from it preventing direct airborne contamination. According to Stokes' law[27] which describes the terminal settling velocity of small particles, such an effect should theoretically be present at the CO_2 flows used for de-airing and for the airborne particles in question.[28–31]

Our experiments incorporated various constraints. We did not study higher CO_2 flows than

10 L/min which are not used in cardiothoracic surgery as 10 L/min provides efficient de-airing of the cardiothoracic wound cavity.[18,19,22] The position of the insufflation device at the acute end of the wound cavity model was chosen because we wanted to study whether the contamination varied between different distances from the device, and as we usually position the CO_2 insufflation device at the caudal end of the wound, thus avoiding interference with surgery.[22]

Bacteriological wound sampling methods, such as wound washout[24,26] and the use of absorption swabs or pads,[13] are not quantitative and do not differentiate between direct and indirect wound contamination.[26] Sedimentation plates are used in vivo for assessment of direct airborne contamination close to the surgical wound. However, applying such a plate inside the wound cavity would be clearly impracticable during surgery. We did not carry out simulated surgery in a fully ventilated operating room as this would provide insufficiently low contamination rates on a small 9 cm agar plate.[23,31] In order to increase the sensitivity of our settle plate sampling method the experiment was carried out in a place where there were people in activity outside the operating room.[32] The differences in contamination rates in the controls between the three experiments were therefore most probably due to differences in number and activity of the people present in the facilities. We used paired comparisons throughout to correct for this. Paired comparisons and the use of a standardized symmetric wound model facilitated the detection of differences in contamination rates.

The study showed that the open-ended tube substantially increased the rate of airborne contamination on the distal agar plate exposed to the CO_2 jet to a rate almost four times that of the control [Figure 3(a)]. Most likely, the jet dragged down ambient room air and ejected airborne particles on to the agar plate.

The gas-diffuser produced a protecting effect against airborne contamination on both agar plates in the model, both with air and with CO_2 [Figure 3(b)]. However, insufflation of CO_2 provided better protection than insufflation of air. As CO_2 is not bactericidal at room temperature and atmospheric pressure,[33] this difference is most probably related to the greater density of CO_2. According to Stokes' law, the greater density of CO_2 should only marginally decrease the settling velocity of airborne particles, as their density is much greater than that of gas. The different protective effects may thus be explained by different flow patterns. Due to its greater density, CO_2 acts like a liquid in the cavity. Proximal to the gas-diffuser the contamination rate in comparison with the control was 28% with air, which was almost as low as with CO_2 (24%). However, on the distal agar plate the contamination rate was 60% with air and 44% with CO_2. Thus, the greater the density of the gas, the longer is the range of the protective effect.

Due to increased upwards gas velocity at the wound opening, the airborne contamination rate, should be reduced if the CO_2 flow is raised from 5 to 10 L/min.[27] In the studied wound model this in its turn reduced the average contamination rate from 30% to 22% compared with the control. Thus, the relation between flow and contamination rate seems to be non-linear, in a way that a further doubling of the flow will have less effect on the airborne contamination rate. This may be due to the non-linear size distribution of the airborne particles that carry micro-organisms.[30] The flow increase had a greater effect on the distal plate than on the proximal pate [Figure 3(c)]. This indicates that a further increase of the CO_2 flow will make a difference at a greater distance from the gas-diffuser, but not at close range where the contamination rate is already low.

Our experimental study has several clinical implications. First, open-ended tubes should not be used for gas insufflation into a surgical wound due to the increased risk of airborne contamination in the area that is exposed to the jet. Conversely, insufflation with a gas-diffuser will most likely decrease the contamination rate. Furthermore, at close range air and CO_2 are almost equally effective at a flow of 5 L/min and air may thus be useful for protection of small surgical wounds. However, although air insufflation may be effective at high flows and at close range, air should not be used in cardiac surgery when there is a risk of air embolism. The contamination rate during insufflation was lower close to the gas-diffuser. It may therefore be advantageous to position it near regions that are most prone to infections, as long as the gas-diffuser is positioned inside the wound cavity.[22]

Although the bulk of airborne particles can be deflected from a wound, it is probably difficult to achieve a contamination rate of 0% at reasonable insufflation flows, as there may always be a proportion of larger airborne particles[28,29] that have much greater settling velocities than the upward gas velocity achieved. As an increased CO_2 flow from 5 to 10 L/min significantly decreased the contamination rate, a flow of 10 L/min is preferable for wound ventilation in cardiac surgery with a complete sternotomy. Furthermore, making the wound opening smaller can in theory increase the efficiency of the wound ventilation, due not only to

a smaller exposed area but also to an increased upward gas velocity.

In conclusion, intraoperative wound ventilation with CO_2 in the cardiothoracic wound using a gas-diffuser may not only prevent air embolism, but may also significantly reduce the risk of airborne contamination and postoperative wound infection in cardiac surgery. In contrast, insufflation with an open-ended tube may substantially increase these risks.

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