What Is the Optimal Device for Carbon Dioxide Deairing of the Cardiothoracic Wound and How Should It Be Positioned?

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Objectives: To compare recently described insufflation devices for efficient carbon dioxide (CO₂) deairing of the cardiothoracic wound and to determine the importance of their position.

Design: Experimental and clinical.

Setting: A cardiothoracic operating room at a university hospital.

Participants: A full-size torso with a cardiothoracic wound and 10 patients undergoing cardiac surgery.

Interventions: Insufflation of CO₂ into the wound cavity at 2.5, 5, 7.5, and 10 L/min with a multiperforated catheter and a 2.5-mm tube with either a gauze sponge or a gas-diffuser of polyurethane foam at its end. The devices were tested when positioned at the level of the wound opening and 5 cm below and after exposure to fluid.

Measurements and Main Results: Deairing was assessed by measuring the remaining air content at the right atrium. With the multiperforated catheter, the gauze sponge, and the gas-diffuser, the lowest median air content in the torso was 8.4%, 2.5%, and 0.3%, respectively (p < 0.001), when positioned inside the wound cavity. When exposed to fluid, the gauze sponge and the multiperforated catheter immediately became inefficient (70% and 96% air, respectively), whereas the gas-diffuser remained efficient (0.4% air). During surgery, the gas-diffuser provided a median air content of 1.0% at 5 L/min, and 0.7% at 10 L/min.

Conclusions: For efficient deairing, CO₂ should be delivered from within the wound cavity. The gas-diffuser was the most efficient device. In contrast to a gas-diffuser, a multiperforated catheter or a gauze sponge is unsuitable for CO₂ deairing because they will stop functioning when they get wet in the wound.

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METHODS

The multiperforated silicone catheter that was tested had a length of 50 cm and a diameter of 3 mm. It had an open end and 20 elliptical holes, 3 mm × 5 mm wide, placed in a spiral around the distal 25 cm of the catheter. The device consisted of a gauze sponge (standard gauze, size 1, approximately 20 mm × 20 mm, Klinidrape, Mölnlycke Health Care AB, Sweden) attached in front of a 2.5-mm tube. Finally, the gas-diffuser (Cardia Innovation AB, Stockholm, Sweden) consists of a plastic 2.5-mm tube with a diffuser (18 mm × 14 mm) at its end. It is made of soft polyurethane foam with open cells. The CO₂ flow was measured with a back-pressure-compensated flow-meter, and the degree of air displacement was assessed by analyzing the O₂ concentration in the remaining air.

The deairing efficiency of the insufflation devices was studied in an anatomic torso, with an open cardiothoracic wound containing a silicone replica of a collapsed heart and great vessels. The torso was positioned on the operating table of a normally ventilated operating room for cardiac surgery with airflow from the ceiling downward to the operating table at approximately 2,500 m³/h.

First, the deairing efficiency of the insufflation devices was studied when they were positioned at the level of the wound opening. The multiperforated catheter was attached along the edge of the sternotomy, starting on the patients’ right side and extending cranially and back on the left side. The end of the 2 other devices was positioned at the wound opening above the diaphragm, pointing to the center of the wound cavity but not toward the site of O₂ measurement. Secondly, the study was repeated with the devices positioned inside the wound cavity. The multiperforated catheter was positioned at the bottom of the pericardial well, starting inferiorly on the patient’s right side and extending above the aortic cannulation site and down the left side, as described by Webb et al. The end of the 2 other insufflation devices was placed 5 cm below the wound opening adjacent to the diaphragm, pointing to the center of the wound cavity but not toward the site of O₂ measurements. It was always kept 8 cm from the gauze sponge and the gas-diffuser. CO₂ was insufflated at a flow of 2.5, 5, 7.5, and 10 L/min.

Thirdly, the deairing efficiency of the gauze sponge and the gas-diffuser was assessed after having been briefly immersed in water during CO₂ insufflation. The multiperforated catheter was exposed to water at the bottom of the wound cavity during CO₂ insufflation. The...
CO2 flow was set at 10 L/min because it is likely that the studied devices will resist fluid exposure better at a high flow.

The air content was measured during steady state and in the absence of surgical maneuvers, at the topmost part of the right atrium 5 cm below the sternal wound edge. A stable O2 concentration was considered present when values were fluctuating around a constant value for 30 seconds. The O2 concentration was then recorded 10 times in succession, once every 5 seconds (n = 10). Before every change of CO2 flow or insufflation device the remaining CO2 in the model was removed with the help of a simple surgical suction device.

The insufflation device found most efficient in the torso, the gas-diffuser, was further studied in 10 patients undergoing cardiac surgery with complete sternotomy. Eight patients underwent coronary artery bypass surgery, and 2 had a valve replacement. There were 6 men and 4 women with a median age of 66.5 years (range 49-74). Their wound opening had a median length and width of 18 cm (range 16-22 cm) and 10 cm (range 9-11 cm), respectively. The gas-diffuser was positioned inside the wound cavity as described above. CO2 was supplied to the opening had a median length and width of 18 cm (range 16-22 cm) and 10 cm (range 9-11 cm), respectively. The gas-diffuser was positioned inside the wound cavity as described above. CO2 was supplied to the wound at a flow of 5 and 10 L/min, respectively. The air content was measured immediately above the right atrium at a median depth of 5 cm (range 3-7 cm) below the wound edge, during full cardiopulmonary bypass when the heart was empty. The measurements were carried out during active surgery without use of suction. When a stable O2 concentration, as defined earlier, was present, the O2 concentration was measured and recorded 5 times in succession, once every 5 seconds. The mean of these 5 values represented the recorded air content for that particular patient. Just as in the experimental part of the study, the remaining CO2 in the wound cavity was removed with the help of the rough sucker before changing the CO2 flow. The Institutional Ethical Committee approved the study, and informed consent was obtained from all patients.

Differences were considered to be statistically significant if p < 0.05. Data are presented as medians and ranges. Mann-Whitney U and Wilcoxon’s tests were used when appropriate. A 2-way analysis of variance (ANOVA), including Bonferroni’s correction to account for multiple testing, was used to compare the flow rates and the different devices used inside the cavity during dry conditions.

RESULTS

At all CO2 flows, all devices were more efficient when positioned inside the cavity, than at the wound opening (p < 0.001, Fig 1). When the multiperforated catheter was positioned inside the cavity, the median air content was 8.4% (range 7.6%-10.2%), 18%, 24%, and 29% at a CO2 flow of 2.5, 5 (p < 0.001), 7.5 (p < 0.001), and 10 L/min (p < 0.01), respectively. When the multiperforated catheter was exposed to water at the bottom of the cavity, the median air content immediately increased to 96% at a CO2 flow of 10 L/min (p < 0.001, Fig 2).

When the gauze sponge was positioned inside the cavity, the median air content was 31.2% (range 28.5%-33.4%), 11.2% (range 9.4%-13.4%), 2.5% (range 2.1%-3.4%), and 2.6% (range 1.8%-3.0%) at a CO2 flow of 2.5 L/min, 5 L/min (p < 0.001), 7.5 L/min (p < 0.001), and 10 L/min (not significant), respectively. These values were lower than the lowest air content obtained with the multiperforated catheter (p < 0.001). After the gauze sponge had been temporarily immersed in water at a flow of 10 L/min, the median air content immediately increased to 70% (range 65.8%-73.5%, p < 0.001).

When the gas-diffuser was positioned inside the wound cavity, the median air content was 7.4% (range 7.0%-7.6%) at a CO2 flow of 2.5 L/min and 0.6% (range 0.5%-0.6%) at a CO2 flow of 5 L/min (p < 0.001). A further drop in median air content to 0.4% (range 0.3%-0.6%, p < 0.01) was seen when the CO2 flow was increased to 7.5 L/min. An increase of the CO2 flow to 10 L/min decreased the median air content to 0.3% (range 0.2%-0.3%, p < 0.001). When positioned 5 cm below the wound edge, the gas-diffuser provided a more efficient deairing than the other devices at the same CO2 flows (p < 0.001). After the gas-diffuser had been temporarily immersed in water, the median air content remained low at 0.4% (range 0.3%-0.6%) at a flow of 10 L/min, a value that was much lower than that obtained with the wet gauze sponge (p < 0.001).

ANOVA was used for analysis of flow and insufflation device when used inside the wound cavity. With 1-way ANOVA, the effect of device on air content was significant (p < 0.001). The following post hoc tests for multiple comparisons showed that all devices were significantly different from each other (p < 0.001). With 2-way ANOVA comparing flows and devices, the interaction device × flow was significant (p < 0.001).

During patient measurements with the gas-diffuser, the median content of remaining air in the wound cavity was 1.0% (range 0.6%-6.3%) at a CO2 flow of 5 L/min and 0.7% (range 0.2%-2.4%) at 10 L/min (not significant).

DISCUSSION

To reduce the number of measurements in patients, the greater part of the study was carried out with a full-scale torso.1314 The shape and size of the model were based on measurements in patients; a close agreement was found between the experimental and patient data, a finding that may be held to support the validity of the study model.

The patients underwent cardiac surgery through a standard sternotomy. They included both coronary artery bypass and valve surgery cases because the size of the wound cavity including the opening area should be the same. Both in patients and in the torso, the air content was measured at the upper level of the right atrium, which is close to the atrial incision during mitral valve replacement. Measuring the air content at the bottom of the wound cavity, as reported by Webb et al,15 may lead to an overestimation of the deairing efficiency because CO2 is heavier than air and tends to accumulate at the lowest point.10

All devices were more efficient when positioned inside the wound cavity than at the wound opening (Fig 1), where the CO2 is more exposed to dilution with ambient air.10 Thus, for maximal effect, any device will have to be placed inside the wound where it comes into contact with fluid.

The multiperforated catheter11 delivers CO2 from multiple holes. Assuming that the outflow is more or less equally distributed over the various holes, their great number will substantially reduce outflow velocity and turbulence. However, when the catheter is curved, the assumption is no longer valid. When CO2 meets a curve in the multiperforated catheter, gas will tend to escape through the first holes in the outer side of the curve. The air content in the wound cavity increased with enhanced CO2 flow, which points to increased turbulence caused by high flow velocities.10 Moreover, a multiperforated...
catheter or a commercial drain is designed to remove blood, which is almost always present at the bottom of the pericardial well.\textsuperscript{11} Once fluid enters the multiperforated catheter, its distal part will be blocked and partially inactivated. This was confirmed in the study (Fig 2).

The use of the gauze sponge\textsuperscript{12} and the gas-diffuser\textsuperscript{10} presupposes the tortuous paths inside it to distribute the CO\textsubscript{2} gas uniformly over a much larger surface, thus reducing gas velocity. Because of their hydrophilic properties gauze sponges are used to absorb fluids. When the gauze sponge gets wet, its structure collapses and its function as a diffuser is lost (Fig 2). Moreover, to avoid air trapping, CO\textsubscript{2} insufflation has to be started even before opening the heart and great vessels and should be continued until closure.\textsuperscript{13} Thus, an undetected absorption of fluid to the gauze sponge will within seconds lead to a significant rise in air content and thus a risk of air trapping. Furthermore, because almost any surgical wound is wet, it would be necessary to measure the CO\textsubscript{2}/air content continuously to know when to exchange the gauze sponge. This is not practical.

By contrast, the gas-diffuser remained efficient after exposure to fluid. The gas-diffuser is made of soft polyurethane foam with open cells. Because of its elastic properties, the foam does not collapse even when soaked, and as gas is blown through the diffuser, large parts of its cell structure will remain open. If the gas-diffuser gets partly covered with tissue or blood, which occurred frequently in the patient study, its function will not be affected. According to the law of least resistance, the CO\textsubscript{2} gas will automatically be redirected inside the diffuser foam to exit through an open part. Thus, the hydro-
phobic and elastic properties of the gas-diffuser will enable it to retain its function in the surgical wound.

Also, under dry conditions, the gas-diffuser produced a higher degree of air displacement than the other devices studied. In terms of lowest median air content, the gas-diffuser was approximately 30 times more efficient than the dry multiperforated catheter and 8 times more efficient than the dry gauze sponge.

The gas-diffuser is efficient when positioned 5 cm below the wound edge. Moreover, the position of the diffuser at the caudal part of the wound causes little interference with surgery (Fig 3). Diffusion between ambient air and CO₂ in the wound cavity, as well as convective air currents around the wound caused by the ventilation system, will increase the air content in the wound unless compensated for with an increased inflow of CO₂. Surgical hand movements may also affect CO₂ deairing. In patients, a CO₂ flow of 5 L/min sufficed to reach a high degree of deairing (1% remaining air) during active surgery. However, the use of rough suction will also deteriorate CO₂ deairing unless the CO₂ flow is equal or higher than the suction rate, which may require a CO₂ flow higher than 5 L/min. Thus, a CO₂ flow of 10 L/min is recommended.
CO₂ has to be delivered from within the cardiothoracic wound cavity to provide a high degree of deairing. Therefore, an insufflation device has to remain efficient when there is fluid present in the open surgical wound. The gas-diffuser was the most efficient device. In contrast to a gas-diffuser, a multiperforated catheter or a gauze sponge is unsuitable for CO₂ deairing because they will stop functioning when they get wet in the wound.

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