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# Comparison of the effectiveness and safety of a new de-airing technique with a standardized carbon dioxide insufflation technique in open left heart surgery: A randomized clinical trial

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**Objective:** We have compared the effectiveness, time required for de-airing, and safety of a newly developed de-airing technique for open left heart surgery (Lund technique) with a standardized carbon dioxide insufflation technique.

**Methods:** Twenty patients undergoing elective open aortic valve surgery were randomized prospectively to the Lund technique (Lund group, n = 10) or the carbon dioxide insufflation technique (carbon dioxide group, n = 10). Both groups were monitored intraoperatively during de-airing and for 10 minutes after weaning from cardiopulmonary bypass by transesophageal echocardiography and online transcranial Doppler for the severity and the number of gas emboli, respectively. The systemic arterial partial pressure of carbon dioxide and pH were also monitored in both groups before, during, and after cardiopulmonary bypass.

**Results:** The severity of gas emboli observed on transesophageal echocardiography and the number of microembolic signals recorded by transcranial Doppler were significantly lower in the Lund group during the de-airing procedure ($P = .00634$) and in the first 10 minutes after weaning from cardiopulmonary bypass ($P = .000377$). Furthermore, the de-airing time was significantly shorter in the Lund group (9 vs 15 minutes, $P = .001$). The arterial pH during the cooling phase of cardiopulmonary bypass was significantly lower in the carbon dioxide group ($P = .00351$), corresponding to significantly higher arterial partial pressure of carbon dioxide ($P = .005196$) despite significantly higher gas flows ($P = .0398$) in the oxygenator throughout the entire period of cardiopulmonary bypass.

**Conclusions:** The Lund de-airing technique is safer, simpler, and more effective compared with the carbon dioxide insufflation technique. The technique is also more cost-effective because the de-airing time is shorter and no extra expenses are incurred. (J Thorac Cardiovasc Surg 2011;141:1128-33)

Systemic air embolism as seen on transesophageal echocardiography (TEE) occurs frequently during open surgery despite improvements in surgical and cardiopulmonary bypass (CPB) techniques.[1-4] The main source of these air emboli is the pulmonary veins.[5] These air emboli continue to show on TEE for as long as 28 minutes after weaning from CPB and are one of the contributing factors for neurocognitive adverse events.[3,6,7] In addition, they can cause transient and permanent neurologic deficits and induce ventricular dysfunction and life-threatening arrhythmias.[7-10] Various de-airing techniques, such as the Trendelenburg position of the patient, partial side clamping of the ascending aorta, and flooding of the cardiothoracic cavity with $CO_2$, are frequently used in combination with different vents to evacuate the retained air in the left side of the heart.[11-14] However, the results are not optimal.[1,15-17] Transcranial Doppler (TCD) studies have revealed that large amounts of cerebral microembolic signals (MES) are recorded during the de-airing process, particularly when the heart starts to eject blood into the systemic arterial circulation.[14,18] Recent reports have shown that insufflation of $CO_2$ into the cardiothoracic cavity reduces systemic air embolism significantly during open surgery.[19-21] However, there is a potential hazard of $CO_2$-induced systemic acidosis from prolonged insufflation of $CO_2$ in the operating field.[22]

We have developed a de-airing technique that was shown to be significantly better than the conventional manual de-airing technique.[18,23] We have now compared the effectiveness and safety of our de-airing technique with a standardized $CO_2$ insufflation technique in routine open left heart surgery using intraoperative TEE, TCD, and blood gas analyses.

## MATERIALS AND METHODS

After approval by the hospital ethical committee, the study was registered under the online protocol registration system with clinical trial registry

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**Abbreviations and Acronyms**

$CO_2$ = carbon dioxide
CPB = cardiopulmonary bypass
LV = left ventricle
MES = microembolic signals
$pCO_2$ = partial pressure of $CO_2$
TCD = transcranial Doppler
TEE = transesophageal echocardiography

ID: NCT00934596. Patients scheduled for elective open aortic surgery were included in the study, and an informed consent was obtained from all patients. The following exclusion criteria were applied for all prospective patients: history of carotid artery disease, chronic obstructive pulmonary disease, emphysema, previous thoracic surgery, thoracic trauma, and concomitant left internal thoracic artery grafting. The following intraoperative exclusion criteria were applied: accidental opening of the pleurae during sternotomy in the $CO_2$ group, failure to wean from CPB, and failure to obtain adequate Doppler signals from the middle cerebral arteries. Twenty consecutive patients were randomized to the Lund de-airing technique (Lund group, n = 10) or the $CO_2$ insufflation technique ($CO_2$ group, n = 10). The randomization list was computer generated using the Statistical Analysis System Plan procedure (SAS ver 8.2 proc PLAN SAS Institute, Cary, NC). For each patient, an envelope indicating the de-airing technique to be used was opened in the operating room during induction of anesthesia.

The patients' demographic data are shown in Table 1. The patients were anesthetized and monitored during surgery in a standard manner using intraoperative TEE for all patients. The same ventilator machine was used for both groups during the intraoperative course (Servo-i, Maquet Inc, Solna, Sweden). Surgery was performed using standard median sternotomy. CPB was performed for all patients using a membrane oxygenator (Compact Flow EVO Phiso; Sorin Group USA Inc, Arvada, Colo), an arterial filter (Cobe Century, Sorin Group USA Inc), and polyvinylchloride tubing (silicone tubing in the pump heads). Roller pumps (Stöckert S3, Sorin Group USA Inc) and a heat exchanger (T3, Sorin Group USA Inc) were used in all patients. The right atrium was cannulated for venous drainage, and arterial blood was returned to the aorta. The CPB was established with a continuous blood flow rate of approximately 2.5 L/min/$m^2$ at normothermia. During CPB, patients were cooled to 28°C to 25°C. All patients received antegrade cold blood cardioplegia. The left ventricle (LV) was vented through the apex in all patients using a 15F Polystan LV drainage catheter (Maquet, Solna, Sweden). The vent was prevented from causing accidental suction collapse of the left side of the heart by piercing the vent line with a 1.20 × 50-mm gauge aspiration needle (B-Braun Melsungen A/G, Germany) and leaving the needle in situ.

## Lund De-Airing Technique

Before CPB was started, both pleural cavities were exposed to atmospheric air through small openings in the mediastinal pleurae. After CPB was established the patient was disconnected from the ventilator, allowing both lungs to collapse. After completion of the surgical procedure and closure of the heart, the LV vent was clamped and the aortic root was de-aired. In this study, we modified our previously described de-airing technique[18,23] by applying active suction of the aortic root until it completely collapsed before the release of the aortic crossclamp (Lund technique). The aortic crossclamp was then released and the LV vent opened again. The heart was then defibrillated to sinus- or pacemaker-induced rhythm. After a good cardiac contraction and normal central hemodynamics, the LV preload was gradually and successively increased by reducing the venous return to the CPB circuit, and the vent in the LV-apex increased under TEE monitoring to prevent cardiac ejection. When no air emboli were observed in the left side of the heart, the patient was reconnected to the ventilator and the lungs were ventilated with half of the estimated minute volume using 100% oxygen and 5 cm $H_2O$ positive end-expiratory pressure. The de-airing was continued, and when no air emboli were observed in the left side of the heart, the lungs were ventilated to full capacity and the heart was allowed to eject by reducing the LV vent. The time from the release of the aortic crossclamp to the cardiac ejection was noted (de-airing time before cardiac ejection, Table 2). The de-airing was continued, and the patient was weaned from CPB. The LV vent was clamped in situ provided that TEE continued to show no air emboli in the left side of the heart, and the time was noted again (de-airing time after cardiac ejection, Table 2).

**TABLE 1. Patient demography and preoperative clinical data by group (values shown are median with upper and lower quartiles for continuous variables)**

| | Lund group (n = 10) | $CO_2$ group (n = 10) | *P* value |
|---|---|---|---|
| Age (y) | 70 (59–77) | 71 (56–78) | .942* |
| Male/female | 5/5 | 5/5 | 1.0† |
| Weight (kg) | 72 (65–86) | 80 (71–90) | .511* |
| Height (cm) | 176 (169–182) | 172 (162–181) | .487* |
| Body surface area ($m^2$) | 1.85 (1.76–2.06) | 2.0 (1.76–2.16) | .743* |
| Plasma creatinine preoperative ($\mu$mol/L) | 73 (67–84) | 66 (64–83) | .559* |
| Plasma ASAT preoperative ($\mu$kat/L) | 0.49 (0.44–0.54) | 0.36 (0.32–0.44) | .006* |
| Plasma ALAT preoperative ($\mu$kat/L) | 0.50 (0.42–0.59) | 0.29 (0.26–0.41) | .03* |

*ASAT,* Aspartate amino transaminase; *ALAT,* alanine amino transaminase; *$CO_2$,* carbon dioxide. *Wilcoxon rank-sum test. †Fisher's exact test.

## Carbon Dioxide Insufflation Technique

The pleural cavities were left intact in the $CO_2$ group. During CPB, the patient was ventilated with a minute volume of 1L, at a frequency of 5 per minute and with a positive end-expiratory pressure of 5 cm $H_2O$. Before the cannulation for CPB, the $CO_2$ insufflation was accomplished as follows: $CO_2$ was insufflated into the cardiothoracic wound through a gas diffuser (Cardia Innovation AB) that provided an approximately 100% $CO_2$ atmosphere in the wound.[24] The diffuser was placed in the sternotomy wound at a depth of 5 cm below the skin adjacent to the diaphragm. $CO_2$ flow was set at 10 L/min and continued until 10 minutes post-CPB. Use of coronary and vent suction was restricted to a minimum to maintain adequate $CO_2$ concentration in the cardiothoracic cavity. Care was also taken to ensure that the diffuser was not soaked with blood during the course of surgery. After completion of the surgical procedure and closure of the heart, the heart and lungs were passively filled with blood from the CPB circuit. The heart was massaged gently, and the left side was de-aired continuously through the LV apical vent. Full ventilation was then resumed, the LV vent was clamped, and the aortic root was de-aired by active suctioning until it collapsed completely. The aortic crossclamp was then released, and the LV vent was opened again. The heart was defibrillated to sinus- or pacemaker-induced rhythm. After good cardiac contraction and normal central hemodynamics were achieved, the LV preload was gradually and successively increased by reducing the venous return to the CPB circuit, and the de-airing continued through the vent in the LV apex under TEE monitoring. When no gas emboli were observed in the left side of the heart, the LV vent was reduced and the heart was allowed to eject; the time was noted (de-airing time before cardiac ejection, Table 2). De-airing was continued, and when no further gas emboli were observed in the left side of the heart, the patient was weaned from CPB and the LV vent was clamped in situ. The time was noted again (de-airing time after cardiac ejection, Table 2).