Concentration of Insufflated Carbon Dioxide During Open Heart Surgery

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Disclosure statement:
Authors have no disclosures

Funding statement:
This study was supported by funds from the Department of cardiothoracic Surgery, Stanford School of Medicine, Stanford University

IRB: Not applicable

Informed consents statement:
As there are no participants involved in this study, no informed consent is necessary

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Article word count: 749
Glossary of abbreviations

C02: Carbon dioxide
O2: Oxygen

Central Message:
Intracardiac concentration of C02 correlates with flow rates but not with locations. Slow clearance and limited dispersal of C02 maintains safe margin for the procedure time and for surgeon exposure

Central picture legend:
Intracardiac C02 concentration options and its concentration above the surgical field
Introduction:
During open chamber heart surgery, carbon dioxide (CO₂) is insufflated in the field to replace the air and lower the risk of air embolism. Prior studies have simply evaluated the levels of CO₂ only in the surgical field. The objective of this research project was to evaluate the levels of CO₂ and O₂ inside the heart under various insufflation conditions, as well as effect of other maneuvers such as using strong suction on these gas concentrations. This study provides unique insights on CO₂ insufflation during cardiac surgery, which might enhance patient safety and surgical outcome.

Methods:
In order to simulate an open-chamber heart surgery, the study used a heart model and a custom-made phantom of the chest with a pericardial cavity (Figure 1A). Given the size, shape and ethical issues, using real patients to place the sensor in the ventricle was not possible and therefore no actual human subjects participated in this study. To enable open communication and replicate an open chamber heart surgery, the model's aorta was tunneled towards the left ventricular chamber. Under various CO₂ insufflation situations, the levels of CO₂ and O₂ were monitored in the left ventricular chamber. A CO₂ sensor (SCD30, Sensirion®, Stäfa Switzerland) and a Gravity: I2C O₂ Sensor (DFRobot®, Electromaker, Poole, England, were connected to an Arduino microcontroller to read the concentrations of the CO₂ and O₂ respectively. Sensors were inserted into the left ventricular chamber to measure the CO₂ and O₂ concentrations at several insufflation cannula sites and flows, as well as during the use of strong suction. To investigate whether CO₂ has any hazardous effect on surgeon, CO₂ concentrations were measured at 10, 20, and 30 cm above the surgical field, as well as at the level of the surgeon's face (Figure 1B). All measurements were taken at specified time intervals to determine the rate of CO₂ clearance from
the heart chamber after discontinuation of Co₂ insufflation. Descriptive statistics only was used
to present the readings from the sensors.

**Results**
Under standard Co₂ insufflation (5 L/min, lower midline corner of the pericardium), the
intracardiac Co₂ reached to 40000 ppm (upper range of the sensor) in 27 seconds and O₂ reached
to lowest level of 8% in 236 seconds. The time taken to reach the maximal intracardiac Co₂
concentration correlated strongly with higher flow rates (Figure 2A). Similarly, the clearance of
Co₂ was slowest for lower flow rates with complete clearance in 3 minutes (Figure 2B). The
speed of decline in intracardiac O₂ concentration was similar in all flow rates, plateauing in 1
minute, however these plateau levels correlated with the Co₂ flow rates (Figure 2C). Upon
discontinuation of Co₂ insufflation, intracardiac O₂ levels reached a plateau, which was
consistent across all flow rates within 2 minutes (Figure 2D).
Placement of Co₂ line in other locations within the pericardial well did not change the above
parameters (Figure 1A). Contrary to common belief, the use of strong suction in the field did not
cause significant changes in intracardiac Co₂ and O₂ concertation, varying less than 1% in any O₂
concentration.
Co₂ concentration measured at 10, 20 and 30cm above the surgical field were 2580, 1130 and
922 ppm, respectively, and the concentration at the level of surgeon’s face was similar to
ambient air (540 ppm at baseline), (Figure 1B).

**Discussion:**
To the best of our knowledge, this is the first study to measure the intracardiac Co₂ and O₂
levels. With conventional CO₂ insufflation of 5 L/min in the lower mid-corner of the pericardial
well, maximal displacement of the intracardiac air occurred in approximately 4 minutes and
returned to baseline values after discontinuation of Co2 in 3 minutes. These time intervals might
be of value in timing the Co2 flow. The slow clearance of the heavy Co2, indicates longer
presence of Co2 in the field which might be considered a safety margin for deairing process. As
opposed to pericardial Co2 concentration which is affected by flow rates and cannula location [1-
2], this study shows the intracardiac Co2 is influenced only by flow rates. The correlation
between lower intracardiac O2 and Co2 insufflation flows might be explained by the easier entry
of Co2 into heart chamber by higher flow rates.

Conclusion
Intracardiac Co2 concentration strongly correlates with insufflation flows. Different locations of
Co2 cannula and using suction does not affect the efficiency of Co2 insufflation. It takes up to 3
minutes for Co2 to be cleared from the heart chamber. The risk of breathing Co2 from
insufflation of Co2 in the field is negligible.
References


**Figure Legends:**

**Figure 1.**
A: setup of the experiment with implantation of sensors in the left ventricle of the cardiac phantom with Co2 insufflation cannula at 4 different positions, B: Co2 concentration at different levels above the surgical field.

**Figure 2.**
Dynamics of intracardiac carbon dioxide and oxygen concentration with different carbon dioxide insufflation flow rates, Co2= carbon dioxide, O2= Oxygen, PPM= Particles Per Million.