Concentration of insufflated carbon dioxide during open cardiac surgery

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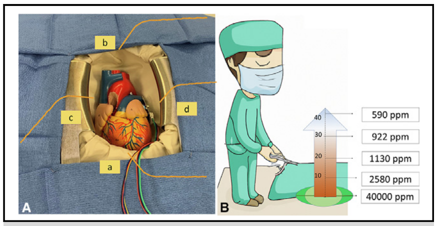

Intracardiac Co_2 concentration options and its concentration above the surgical field.

CENTRAL MESSAGE

Intracardiac concentration of Co_2 correlates with flow rates but not with locations. Slow clearance and limited dispersal of Co_2 maintain a safe margin for the procedure time and surgeon exposure.

During open chamber heart surgery, carbon dioxide (Co_2) is insufflated in the field to replace the air and lower the risk of air embolism. Prior studies have simply evaluated the levels of Co_2 only in the surgical field. The objective of this research project was to evaluate the levels of Co_2 and oxygen (O_2) inside the heart under various insufflation conditions, as well as the effect of other maneuvers such as using strong suction on these gas concentrations. This study provides unique insights on Co_2 insufflation during cardiac surgery, which might enhance patient safety and surgical outcome.

MATERIALS AND METHODS

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 1, *A*). 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 toward the left ventricular chamber. Under various Co_2 insufflation situations, the levels of Co_2 and O_2 were monitored in the left ventricular chamber. A Co_2 sensor (SCD30, Sensirion) and a gravity I2C O_2 Sensor (DFRobot, Electromaker) were connected to an Arduino microcontroller to read the concentrations of the Co_2 and O_2, 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 Co_2 has any hazardous effect on surgeon, Co_2 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 1, *B*). All measurements were taken at specified time intervals to determine the rate of Co_2 clearance from the heart chamber after discontinuation of Co_2 insufflation. Descriptive statistics were used to present the readings from the sensors.

RESULTS

Under standard Co_2 insufflation (5 L/min, lower midline corner of the pericardium), the intracardiac Co_2 reached to 40,000 ppm (upper range of the sensor) in 27 seconds and O_2 reached to the lowest level of 8% in 236 seconds. The time taken to reach the maximal intracardiac Co_2 concentration correlated strongly with higher flow rates (Figure 2, *A*). Likewise, the clearance of Co_2 was slowest for lower flow rates with complete clearance in 3 minutes (Figure 2, *B*). The speed of decline in intracardiac O_2 concentration was similar in all flow rates, plateauing in 1 minute; however, these plateau levels correlated with the Co_2 flow rates (Figure 2, *C*). Upon discontinuation of Co_2 insufflation, intracardiac O_2 levels reached a plateau that was consistent across all flow rates within 2 minutes (Figure 2, *D*).

Placement of a Co_2 line in other locations within the pericardial well did not change these parameters (Figure 1, *A*). Contrary to common belief, the use of strong suction in the field did not cause significant changes in intracardiac Co_2 and O_2 concertation, varying less than 1% in any O_2 concentration.

Co_2 concentration measured at 10, 20, and 30 cm 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 1, *B*).

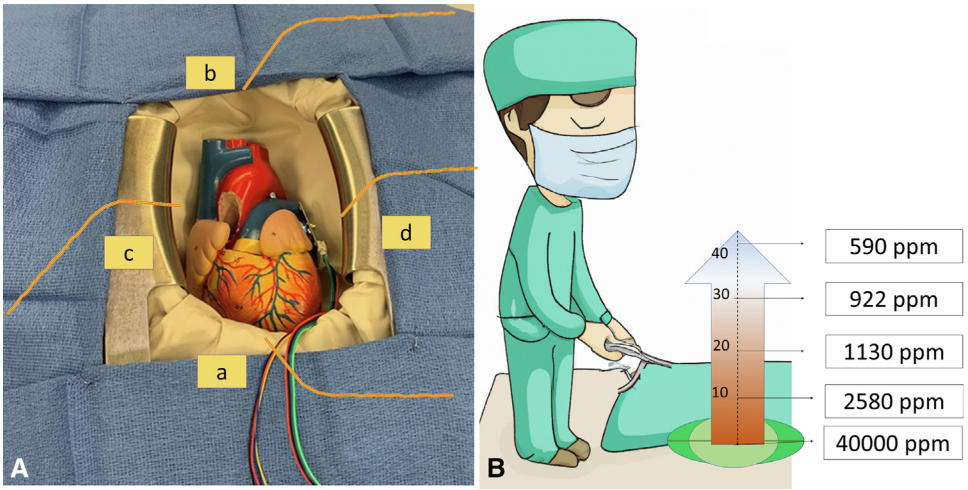

FIGURE 1. A, Setup of the experiment with implantation of sensors in the left ventricle of the cardiac phantom with Co_2 insufflation cannula at 4 different positions. B, Co_2 concentration at different levels above the surgical field.

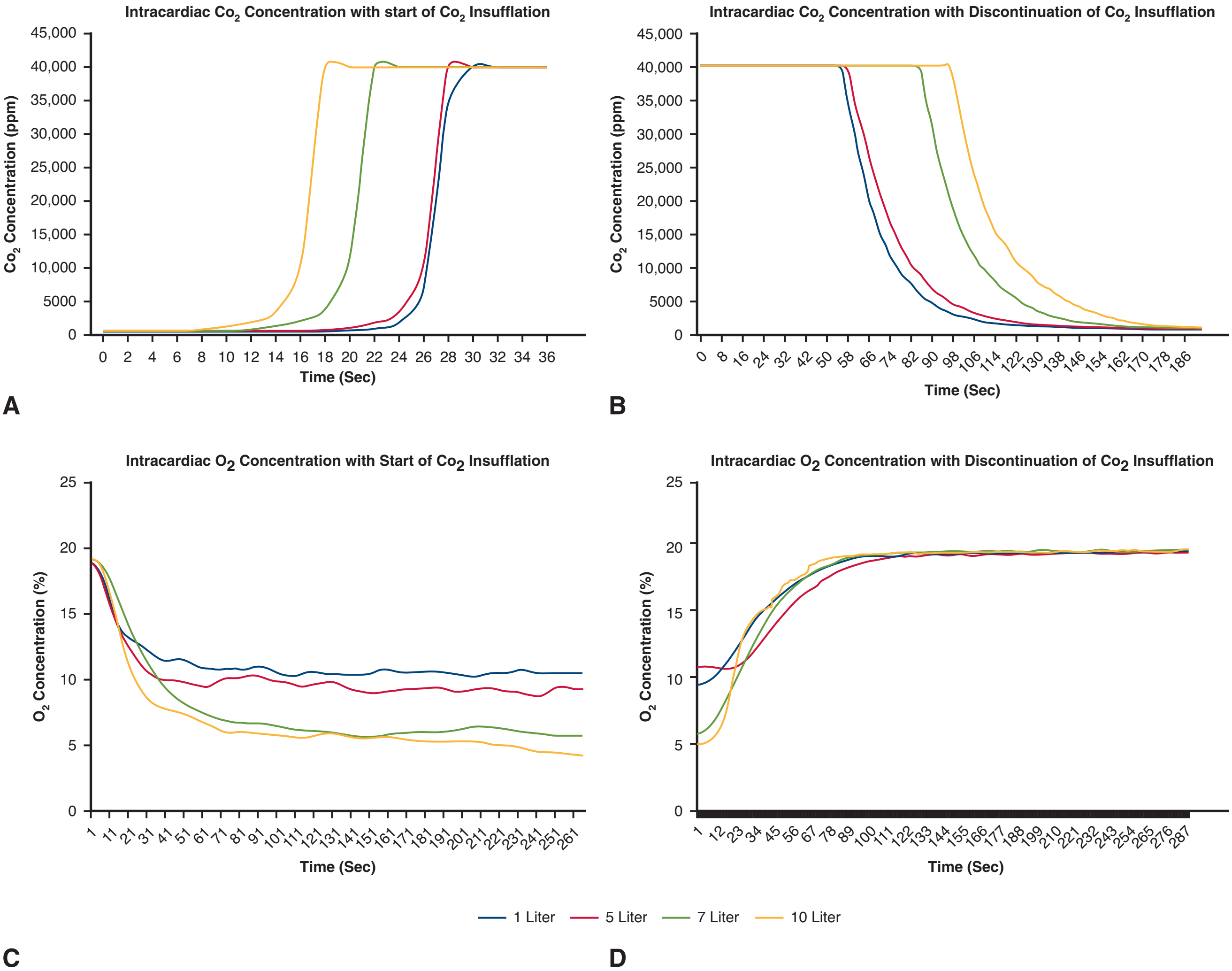

FIGURE 2. Dynamics of intracardiac Co_2 (A, B) and O_2 (C, D) concentration with different Co_2 insufflation flow rates. *Co_2*, Carbon dioxide; *PPM*, particles per million; *O_2*, oxygen.

DISCUSSION

To the best of our knowledge, this is the first study to measure the intracardiac Co_2 and O_2 levels. With conventional CO_2 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 Co_2 in 3 minutes. These time intervals might be of value in timing the Co_2 flow. The slow clearance of the heavy Co_2, indicates a longer presence of Co_2 in the field, which might be considered a safety margin for the deairing process. As opposed to pericardial Co_2 concentration, which is affected by flow rates and cannula location,[1,2] this study shows the intracardiac Co_2 is influenced only by flow rates. The correlation between lower intracardiac O_2 and Co_2 insufflation flows might be explained by the easier entry of Co2 into the heart chamber by higher flow rates.

CONCLUSIONS

Intracardiac Co_2 concentration strongly correlates with insufflation flows. Different locations of Co_2 cannula and using suction does not affect the efficiency of Co_2 insufflation. It takes up to 3 minutes for Co_2 to be cleared from the heart chamber. The risk of breathing Co_2 from insufflation of Co_2 in the field is negligible.

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