BRIEF REPORT

REVISED Workplace exposure to carbon dioxide during routine laparoscopy – is it safe? [version 2; peer review: 2 approved]

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Abstract
Background: Minimally invasive surgeries have increased dramatically during the last decades. Carbon dioxide (CO_2) is the gas used for insufflation during laparoscopies, creating space and visibility. The CO_2 leaks into ambient air through ports where instruments are inserted. If the CO_2 reaches a certain concentration it affects personnel health. There are national occupational exposure limits (OEL) for CO_2, including a level limit value (LLV) of 5000 ppm. We are not aware of any previous studies addressing occupational exposure to CO_2 during laparoscopies. The aim of this study was to assess the compliance to national OELs for CO_2 during laparoscopies.
Methods: A gas detector was placed in the breathing zone of personnel in the operating theatre. The detector measured CO_2 concentrations every tenth minute during laparoscopies in three locations.
Results: During 27 laparoscopies, the measured CO_2 reached a maximum concentration of 1100 ppm, less than one fourth of the LLV. Median CO_2 concentration was 700 ppm.
Conclusion: Results show that the occupational exposure to CO_2 during laparoscopies is well below set OELs. Our findings support personnel safety associated with routine use of CO_2 during laparoscopies.

Keywords
Ambient air, Carbon dioxide, Laparoscopy, Minimally invasive surgery, Occupational exposure, Work place exposure

Open Peer Review

Reviewer Status ✓ ✓

	Invited Reviewers	
	1	**2**
version 2 (revision) 21 Sep 2020	✓ report	✓ report
version 1 08 Jun 2020	✓ report	? report

1. **Colin F. Royse**, University of Melbourne, Parkville, Australia
2. **Jakob Walldén**, Umeå University, Umeå, Sweden
Sundsvall Hospital, Sundsvall, Sweden

Any reports and responses or comments on the article can be found at the end of the article.

Corresponding author: Jan G. Jakobsson (jan.jakobsson@ki.se)

Author roles: af Petersens M: Data Curation, Formal Analysis, Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Andersson Fenger-Krog F**: Conceptualization, Investigation, Methodology, Writing – Original Draft Preparation; **Jakobsson JG**: Conceptualization, Investigation, Methodology, Project Administration, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: Jan G Jakobsson is a paid consultant as a safety physician at Linde Healthcare. Gas monitors used during the study were provided by Linde Healthcare.

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First published: 08 Jun 2020, **9**:571 https://doi.org/10.12688/f1000research.24230.1

REVISED **Amendments from Version 1**

The manuscript has been revised taking the comments of referee into account.

The average ambient air CO_2 that now exceeds 400 ppm has been added and discussed.

The effective ventilation, air change in operating theatres are further addressed and discussed.

The accuracy of the measuring device is further commented.

Any further responses from the reviewers can be found at the end of the article

Introduction

Minimally invasive surgical techniques aim to achieve surgical therapeutic goals with minimal trauma[1]. Minimal invasive surgery (MIS) has increased dramatically and is today well-established for huge numbers of procedures. During all forms of MISs, e.g. classic laparoscopy, gas insufflation is the most commonly used technique to create enough space to allow surgery[2]. The preferred, most commonly used, gas for insufflation is carbon dioxide (CO_2)[3]. Characteristics of a perfect gas for insufflation include being colorless, incombustible, easily soluble in blood, non-toxic, inexpensive and easily removed from the body. CO_2 is the gas that best matches these characteristics. To establish a gaseous cushion, an insufflator is used to pump CO_2 into the abdominal cavity or other surgical field. CO_2 will leak into the ambient air from the cavity where the instruments later are inserted, hence the CO_2 concentration in ambient air in the operating theatre may be elevated and thus potentially cause personnel health concern.

Hypercapnia

Symptoms of acute hypercapnia include flushed skin, headaches and sweating. Higher CO_2 concentrations in ambient air may also cause anxiety and dizziness. High levels may further cause confusion and shortness of breath and eventually dimmed sight, tremor, unconsciousness or even death[4,5]. The individual response to elevated CO_2 concentrations in ambient air varies depending on the time of exposure and CO_2 concentration[4].

Recent work suggests that chronic exposure to higher concentration of CO2 may cause negative health effects, potentially having effects on fertility[6,7].

Occupational exposure limits

To prevent ill health, many countries have provisions regarding the highest acceptable concentrations of air pollutants at workplaces. The highest acceptable average concentration of an air pollutant in workplace air, calculated as time weighted average is known as the occupational exposure limit (OEL). There are two often used OEL values, the level limit value (LLV) and the short-term exposure limit (STEL). LLV is the OEL value for exposure during a working day, normally eight hours. STEL is the OEL value for a reference period of 15 minutes exposure[8]. The Swedish OELs are based on the EU's binding OELs, which includes an LLV of 5000 ppm for CO_2[9]. The US National Institute for Occupational Safety and Health (NIOSH) has a similar level[10]. The LLV is binding, unlike the STEL for CO_2 at 10000 ppm which is the recommended highest value[8].

Personnel workplace safety is of huge importance and OELs has been set to secure good working condition, securing personnel health. The workplace CO_2 concentrations may constitute a safety risk. We are not aware of previous studies explicitly addressing the adherence to OELs in operating theatres (OT) during routine use of CO_2 for insufflation during laparoscopies.

Aim

The aim of this study was to assess the occupational exposure to CO_2 in OTs during laparoscopies to verify the compliance to set national (Swedish) OELs.

Methods

Study design and context

This was an explorative, non-interventional study of CO_2 concentrations in ambient air during laparoscopies conducted at Danderyd Hospital during October 2019. The CO_2 concentration was measured at three locations: old general surgery ward (OGSW; n=2), new general surgery ward (NGSW; n=1) and day surgery unit (DSU; n=1). The ventilation differed between the locations. In the two older OTs, the air volume flow was 710 L/s (liter/second) and 650 L/s. The air volume flow in the new OT was 2160 L/s during surgeries and 100 L/s during basic ventilation. In the DSU, the air volume flow was between 720 and 2160 L/s.

Surgeries

The laparoscopies included in this study were aggregated into three groups based on the type of surgery: cholecystectomies, hernia repairs and intestinal surgeries. Five groups (A-E) were created depending on the type of surgery and the location: cholecystectomy DSU (A), cholecystectomy NGSW (B), hernia repair NGSW (C), intestinal surgery OGSW (D), intestinal surgery NGSW (E) (Table 1).

Data collection

A gas detector (**TM Dräger X-am 5600, Germany**) was used to record point measurements of CO_2 concentrations during the surgeries. This detector has a measurement range of 0–5%, hence the full-scale value is 5% (50000 ppm). The manufacturer of the sensor states an accuracy of ±800 ppm if the CO_2 concentration is 25000 ppm or less. The resolution of the sensor is 100 ppm, thus the scale is divided into 500 equal divisions (400 ppm, 500 ppm, 600 ppm etc.). The exact value displayed depends on the span value set during calibration.

The primary outcome of the study was the concentration of CO_2 in ambient air during MIS. The gas detector was positioned at a height of 153 cm in the OT at the IV pole on the right side of the patient. The CO_2 concentration was noted manually every tenth minute starting on the hour. Observations were collected from the point measurement before the start of

Table 1. Summary of characteristics and possible confounding factors of group A–E. Surgery duration is presented as mean and standard deviation. Intra-abdominal pressure, number of people in the operating theatre and carbon dioxide concentration are presented as median and range. Number of people in operating theater excludes the patient.

	Group	Location	Surgeries (n)	Observations (n)	IAP (mmHg)	People in OT (n)	Duration (min)	Gas detector CO_2 (ppm)
Cholecystectomy	A	DSU	6	52	12 [12–12]	7 [5–7]	77 (19)	600 [400–600]
	B	NGSW	3	30	12 [12–12]	7 [6–7]	90 (26)	700 [600–1100]
Hernia repair	C	NGSW	4	40	12 [12–14]	6 [6–7]	90 (22)	700 [600–1000]
Intestinal surgery	D	OGSW	2	35	13 [12–14]	9 [7–10]	165 (120)	600 [600–1000]
	E	NGSW	5	57	14 [12–14]	7 [5–8]	113 (85)	700 [600–800]
Total			20	210				700 [400–1100]

IAP intra-abdominal pressure, CO_2 carbon dioxide, *OT* operating theatre, *OGSW* old general surgery ward, *NGSW* new general surgery ward, *DSU* day surgery unit, *ppm* parts per million

surgery until the point measurement after the end of surgery. Start and end of surgery were determined by start- and endpoint as noted by the nurse anesthetist in the medical record.

One of the secondary outcomes was the CO_2 concentration at different heights in the OT. During a laparoscopic hernia repair in the NGSW (group C) the gas detector was placed as previously described. During the first two observations (20 minutes) the detector was placed at a height of 153 cm and was then moved to 105 cm for the next two observations. The following two observations were collected at a height of 15 cm and the detector was then moved back to a height of 153 cm. Observations were collected by changing the height as described every 20 minutes until the end of surgery.

The other secondary outcome of the study was the maximum concentration of CO_2 when gas is allowed to freely enter the OT by disconnecting the insufflation tube from the insufflator. This was conducted in an OT in the NGSW. The gas detector was placed as described previously. The insufflator was set at high flow and the intra-abdominal pressure (IAP) was set to 14 mmHg. The central gas was turned on for five minutes and the highest observed CO_2 concentration, the CO_2 concentrations at the beginning and end of the attempt were noted manually. The attempt was conducted three times, the first time with basic ventilation and the third time with operation ventilation.

Statistical analysis

Data is presented as mean, standard deviation, or median and range as applicable. For descriptive analysis and Kruskal-Wallis test, Microsoft Excel (version 16.32, 2019) was used. Descriptive analysis was performed to show measured CO_2 concentrations, characteristics and possible confounding factors among the five groups. Kruskal-Wallis test was used to analyze if there was a significant difference among the three different heights where the CO_2 concentration was measured. A P value <0.05 was considered statistically significant. To illustrate CO_2 concentrations in different groups, box plots were created using R programming language (version 3.6.1, 2019-07-05).

Ethical considerations

This was an explorative non-interventional air quality study and the CO_2 concentrations in OTs were monitored only to ensure personnel health. Personnel safety and health is of great importance and this study was significant to assess the personnel safety related to CO_2 in OTs. No patient or personnel data were collected. There was no need for ethical approval. The Head of the Department of Anesthesia and Intensive Care as well as the Head of the Department of Surgery approved the study.

Results

The CO_2 concentration was measured during 20 surgeries where a total of 210 observations were collected with the gas detector. The number of observations in each group ranged from 30 to 57. Possible confounding factors such as the number of people in the OT and IAP showed little variation between groups (Table 1).

During the surgeries, the measured CO_2 concentration showed minor variation. Point measurements from one of the surgeries were selected to show an example of intraoperative variation of CO_2 concentration measured with the gas detector (Figure 1). During this surgery, 65% of the measured CO_2 concentrations were at 600 ppm and observations ranged from 600 to 1000 ppm. Variation of intraoperative CO_2 concentration was occasionally coherent with emptying and insufflations of gas in the peritoneal cavity. All measured CO_2 concentrations during this surgery were less than or equal to 20% of the LLV (Figure 1).

Out of all observations collected in groups A-E, none exceeded 1100 ppm (Figure 2). The CO_2 concentration was 600 ppm or 700 ppm in 81% of the observations (Figure 2). Concentration of CO_2 exceeding 700 ppm was seen in 12% of observations.

The CO_2 concentration during the surgeries was measured at 400–1100 ppm and never exceeded 22% of the LLV at 5000 ppm (Figure 3). Because of the scarce variation in all the groups, sporadic variations are frequently shown as outliers in the box plot.

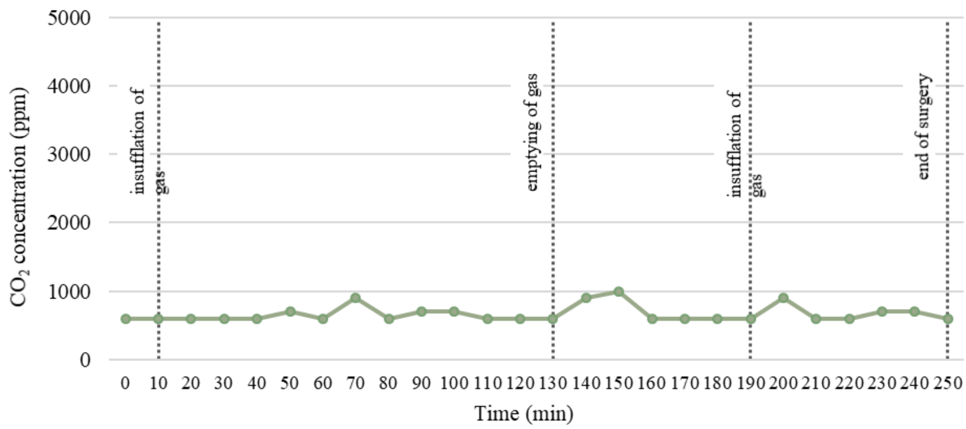

Figure 1. CO2 concentration measured during one entire laparoscopic procedure. (minutes on x-axis and CO2 concentration ppm on Y-axis.

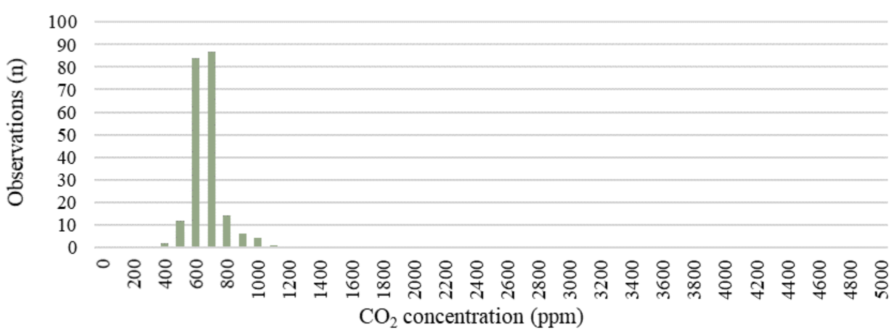

Figure 2. Measured CO2 concentrations during surgery. CO2 concentration measured on x-axis, number of observations on y-axis.

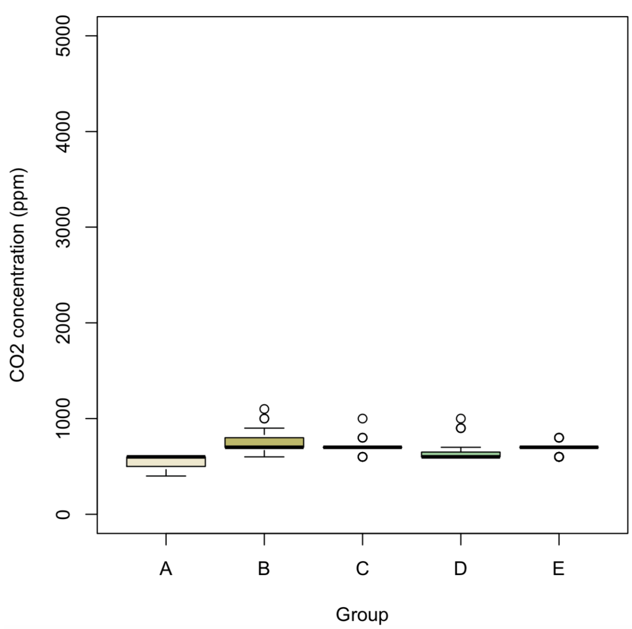

Figure 3. Box plots for CO2 concentration measured during the 5 different surgical procedures. Procedures on x-axis, CO2 concentration on y-axis. A and B cholecystectomy; A Days surgical unit, B in News Surgical unit, C Hernia repair in new surgical unit, D and E Intestinal surgery; D in old surgical unit, E in new surgical unit.

When the CO_2 concentration was measured at different heights in the OT, results of Kruskal-Wallis test showed no significant difference between heights ($\chi^2 = 1.371$, $p = 0.504$).

During the three attempts when CO_2 was allowed to freely enter the OT for five minutes, the highest value measured was 2000 ppm. This value is a fifth of the STEL and less than half of the LLV (Figure 4).

Discussion

The primary aim of this study was to measure the concentration of CO_2 in ambient air during laparoscopies to verify compliance to the set national OELs. During 20 laparoscopies in three different locations, the measured CO_2 concentration did not exceed 1100 ppm, which is less than one fourth of the LLV and one ninth of the STEL. Furthermore, when gas was allowed to freely enter the OT for five minutes, mimicking an accidental user error, the measured CO_2 reached a maximum concentration of two fifths of the LLV. Thus, all measured CO_2 concentrations were well below set OELs, hence the findings are reassuring. Our measured vales must be put into perspective. Ambient air CO2 concentration is today higher than ever before, the global average atmospheric carbon dioxide in 2019 was 409.8 parts per million (ppm for short), with a range of uncertainty of plus or minus 0.1 ppm.

Personnel health is of great importance and it is the obligation of all healthcare organizations to secure proper workplace safety including ambient air quality. However, we are not aware of previous studies reporting CO_2 concentrations during laparoscopies. Air quality indices including CO_2 concentrations have nonetheless recently been studied during other types of MIS in a gastrointestinal endoscopy unit[11]. Similar to our findings, the CO_2 concentration in the procedural area was well below set OELs with a median concentration of 593.1 ppm (range 400–1645.9 ppm).

In our study we measured CO_2 as a direct pollutant. Conversely, like the study in the gastrointestinal endoscopy unit, the CO_2 concentration in other hospital environments has previously been studied as an indicator of air quality rather than as a direct pollutant[12–14]. The ventilation must thus be taken into account. The ambient air average concentration is today high. Additional CO_2 load, the amount of CO_2 added to the ambient air, CO_2 exhaled by subjects in the room and CO_2 from any additional sources, (e.g. from the insufflation of CO_2 gas) and air change, ventilation, are the main factors for secure ambient air quality. CO_2 as an indicator of air quality has also been studied in other environments such as classrooms[15,16]. Overall, results in these studies of hospital environments and classrooms show concentrations considerably lower than the set OELs. The hospital operating room ventilation is most effective as was shown in our testing extensive leakage, caused by a simulated user error.

The results must be put in perspective of some limitations. The gas detector can only assume certain fixed values, thus small changes in concentration were not detected. Nevertheless, it was important in this study to distinguish between measured CO_2 concentrations and national OELs and detection of smaller changes in CO_2 concentration were not needed for this purpose. The device was calibrated but the accuracy of the instrument must also be acknowledged. Still even in a worst case scenario for accuracy the measured levels are well below OEL.

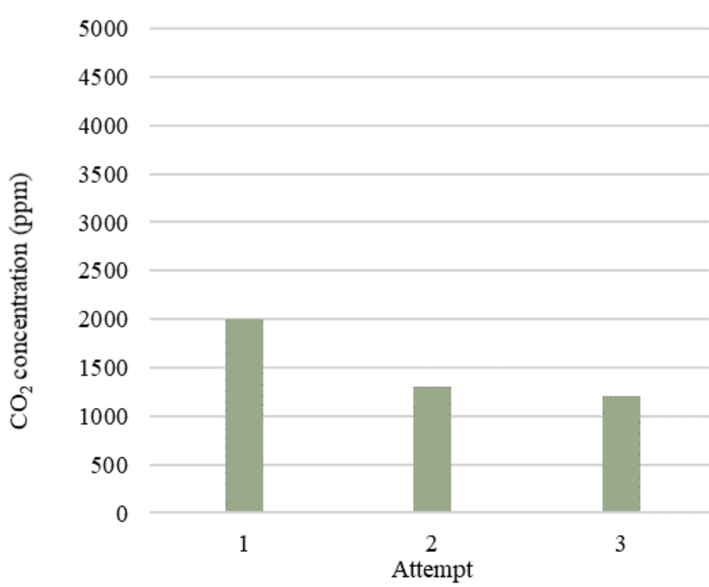

Figure 4. CO2 concentration peak value measured during CO2 release into the operating theater. Attempt on x-axis and peak CO2 concentration ppm on y-axis.

Possible confounding factors include the number of trocars, the ventilation systems, conversion to open surgery, the number of people in the OT and the IAP. Nevertheless, the CO_2 concentration varied little among groups and thus these factors did not seem to have a considerable impact on the concentrations in this study.

Data was handled manually due to the inability to store data and the inability to transfer data to a computer in the gas detector. Concentrations at different heights were only measured during one surgery and differences between heights can therefore not be established. Moreover, concentrations were only measured at one hospital and during rather few surgeries and results may not be generalizable to other hospitals, although all concentrations in the different locations were very low. CO_2 concentrations were only studied at adult surgery departments and because of differences in abdominal cavity volume, amount of CO_2 used and other unrecognized factors, results may be less transferable to children.

In addition, we looked solely at laparoscopies in this study. Other MIS techniques, such as colonoscopies and robotic surgeries, can be performed in other environments or have a longer duration which might affect CO_2 concentrations.

Conclusion

This study shows that the occupational exposure to CO_2 in OTs during laparoscopies is well below set OELs. Our findings also suggest that CO_2 concentrations are distributed the same way at different heights in the OT. Even when gas is freely entering the OT for five minutes, mimicking an accidental user error, the CO_2 concentrations are well below OELs, hence the results are reassuring. Our findings support personnel safety associated with routine use of CO_2 for insufflation during laparoscopy.

Data availability

Underlying data

Open Science Framework: CO2 measurement, https://doi.org/10.17605/OSF.IO/6S5UQ[17].

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Open Peer Review

Current Peer Review Status: ✓ ✓

Version 2

Reviewer Report 25 September 2020

https://doi.org/10.5256/f1000research.29591.r71740

✓ **Jakob Walldén**
[1] Anaesthesia and Intensive Care Section, Umeå University, Umeå, Sweden
[2] Anesthesia and Intensive Care, Sundsvall Hospital, Sundsvall, Sweden

The authors have adressed the issues pointed out in the revision.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Anesthesiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 22 September 2020

https://doi.org/10.5256/f1000research.29591.r71739

✓ **Colin F. Royse**
Department of Surgery, University of Melbourne, Parkville, Victoria, Australia

Amendments are satisfactory.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Anesthesiology, Echocardiography, cardiac surgery outcomes, Quality of recovery after surgery

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 11 September 2020

https://doi.org/10.5256/f1000research.26727.r70136

?

Jakob Walldén

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This is a study evaluating carbon dioxide levels during laparoscopies in operating theaters in relation to occupational exposure limits. The study design and results are clear and easy to understand and the conclusions are sound in relation to the results- carbon dioxide levels are not a health related issue.

However there are a few minor issues I would like to address to improve the manuscript:

- The levels of carbon dioxide detected are low. What are normal background levels? Outdoor, indoor, operating rooms with high ventilation? Please relate your findings and include in the discussion.

- How is CO2 levels affected by the the high ventilation? Is it even possible to detect high levels, are CO2 washed out quickly? Consider including the issue in discussion.

- The accuracy of the method is stated as +/- 800 ppm. This means that there is a possibility that the levels detected at 800 ppm is in the range 0-1600 ppm. The rise in CO2 during flushing shows that sensor work. However, if related to the primary aim, even if the real CO2 levels are in the higher interval, it is far below OEL. Please include briefly in discussion.

- Please use L/min instead of l/min.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Anesthesiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response (*F1000Research Advisory Board Member*) 11 Sep 2020

Jan Jakobsson, Karolinska Institutet Danderyds Hospital, Stockholm, Sweden

Dear Referee.
Thank you for important comments.

- The average ambient air CO2 has passed 400 ppm and is today higher than ever before.
- Operating rooms are indeed well ventilated. Merely a rather limited increase was seen in the operating room CO2 concentration when a 5 minute free release of CO2 accident, user error, was mimicked
- The instrument used was calibrated but the accuracy must of course be acknowledged.

We have now revised and incorporated these important aspects into the discussion.

Competing Interests: Jan Jakobsson is has a contract with Linde as paid drug safety physician

Reviewer Report 13 July 2020

https://doi.org/10.5256/f1000research.26727.r65631

Colin F. Royse

Department of Surgery, University of Melbourne, Parkville, Victoria, Australia

The authors have conducted a safety study to measure the Carbon Dioxide concentration that could be inhaled by staff in the operating room during laparoscopic surgery.

They chose three different locations, each of which have different ventilation and air volume turnover methodologies. They conducted serial assessments over time for multiple surgeries. They also conducted a brief experiment where they ran CO_2 freely into the operating room.

They found that there is little variance between each of the operating locations or types of surgery. Importantly, all will well below the acceptable limits (level limit value of 5000 PPM). It was interesting, that even the range of CO_2 was relatively small, with the maximum amount being around 1100 PPM. When CO_2 is freely introduced into the air, the values were higher- approximating 2000 PPM, which was still well below the level limit value that is mandated in Europe.

This paper adds to our literature of occupational safety. The use of different theatre locations (old and new) with different air volume turnover rates allows this knowledge to be transferred to other locations and hospitals. It is highly unlikely, even with old theatres, that laparoscopic surgery will produce high levels of carbon dioxide, sufficient to affect health care workers.

The conclusion is consistent with the data, and supports that even an accidental user error, where carbon dioxide is freely running into the theatre, is still unlikely to cause a health issue for workers-this is very encouraging data.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

No source data required

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Anesthesiology, Echocardiography, cardiac surgery outcomes, Quality of recovery after surgery

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.