Smoke Evacuation During Laparoscopic Surgery: A Problem Beyond the COVID-19 Period. A Quantitative Analysis of CO_2 Environmental Dispersion Using Different Devices

Surgical Innovation
2022, Vol. 29(2) 154–159

DOI: 10.1177/15533506211014857
journals.sagepub.com/home/sri

Umberto Bracale, MD, PhD[1], Vania Silvestri, MD[1], Emanuele Pontecorvi, MD[1], Immacolata Russo[2], Maria Triassi, MD[2], Elisa Cassinotti, MD, PhD[3], Giovanni Merola, MD[1], Paolo Montuori, MD[2], Luigi Boni, MD[3], and Francesco Corcione, MD[1]

Abstract

Background. The COVID-19 pandemic leads to several debates regarding the possible risk for healthcare professionals during surgery. SAGES and EAES raised the issue of the transmission of infection through the surgical smoke during laparoscopy. They recommended the use of smoke evacuation devices (SEDs) with CO_2 filtering systems. The aim of the present study is to compare the efficacy of different SEDs evaluating the CO_2 environmental dispersion in the operating theater. *Methods.* We prospectively evaluated the data of 4 group of patients on which we used different SEDs or standard trocars: AIRSEAL system (S1 group), a homemade device (S2 group), an AIRSEAL system + homemade device (S3 group), and with standard trocars and without SED (S4 group). Quantitative analysis of CO2 environmental dispersion was carried out associated to the following data in order to evaluate the pneumoperitoneum variations: a preset insufflation pressure, real intraoperative pneumoperitoneum pressure, operative time, total volume of insufflated CO_2, and flow rate index. *Results.* 16 patients were prospectively enrolled. The [CO_2] mean value was 711 ppm, 641 ppm, 593 ppm, and 761 ppm in S1, S2, S3, and S4 groups, respectively. The comparison between data of all groups showed statistically significant differences in the measured ambient CO_2 concentration. *Conclusion.* All tested SEDs seem to be useful to reduce the CO_2 environmental dispersion respect to the use of standard trocars. The association of *AIRSEAL system* and a homemade device seems to be the best solution combining an adequate smoke evacuation and a stable pneumoperitoneum during laparoscopic surgery.

Keywords

laparoscopic surgery, smoke evacuation device, CO_2, COVID-19, SARS-COV-2

Background

Since February 2020, the COVID-19 pandemic led to several debates regarding different aspect of the management of the surgical patient, especially related to the possible risk for healthcare professionals during surgery.

The SARS-CoV-2 has a size range of .06–.14 microns,[1] and it has been found in different part of the human body, including respiratory and gastrointestinal tract, leading to possible multiple ways of transmission.

Previous studies have shown the possible aerosolization of some viral pathogens during laparoscopic surgery.[2-4] So, the operating room (OR) staff could inhale high concentration of CO_2 with aerosolized biological particles.[5] For these reasons, the most important international surgical societies, especially SAGES and EAES, raised the issue of the possible transmission of viral infection through the surgical smoke during laparoscopic procedures.[6]

[1]Department of General Surgery and Surgical Specialty, General and Mini-Invasive Surgical Unit, University Federico II of Naples, Naples, Italy
[2]Department of Public Health, University Federico II of Naples, Naples, Italy
[3]Department of Surgery, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico di Milano, University of Milan, Milan, Italy

Corresponding Author:
Umberto Bracale, Department of General Surgery and Surgical Specialty, General and Mini-Invasive Surgical Unit, University Federico II of Naples, Via Pansini n°5, Naples 80100, Italy.
Email: umbertobracale@gmail.com

In absence of scientific evidence on the possible aerosolization of SARS-CoV-2 in surgical smokes, they recommended the use of smoke evacuation devices (SEDs) with CO_2 filtering systems to reduce this potential risk. It is recommended that these SEDs have an ultra-low particulate air (ULPA) filter able to capture particles of .1 microns and larger.[1] So, regardless to the risk of viral transmission during COVID-19, the use of effective SEDs during surgical procedures seems to be a concern of huge relevance.

The aim of the present study is to compare the efficacy of different SEDs, evaluating the CO_2 environmental dispersion and the pneumoperitoneum stability in the operating theater.

Method

Between April 2020 and February 2021, we prospectively evaluated the data of 4 group of patients on which we used different SEDs or standard trocars: *AIRSEAL® system (S1 group)*, an homemade device (S2 group),[7] an *AIRSEAL® system* + homemade device (S3 group) as suggested by SAGES and EAES,[8] and with standard trocars and without SED (S4 group).

In the first group, we used *AIRSEAL® system.* Unlike conventional insufflators that feature unidirectional flow and cyclical inflation, which momentarily stops for pressure sensing function, the AirSeal® iFS features a filtered circulatory flow design (particles of size equal to 0.01 μm) which not only enables simultaneous insufflation and pressure sensing but also provides constant smoke evacuation.

In the second group, using a standard insufflation system, a homemade device for smoke evacuation[7] was connected to a 10-mm trocar. This SED was assembled connecting a standard electrostatic filter used for ventilation machines which have the great capability of filtering known bacterial and viral loads which have a diameter smaller than that of SARS-CoV-2. This filter can be connected via standard tubing to the trocar evacuation port. In order to connect the filter to the tubing, we use the endotracheal tube connector (Figure 1). The homemade device was connected via standard tubing to an active suction system in order to maintain a constant low-pressure wall suction during the procedure.

In the last group, we used an *AIRSEAL® system* associated with a homemade SED as suggested by the SAGES-EAES Guidelines.[6]

The CO_2 measurements were carried out by placing a sterile probe of a multi-gas monitor as close as possible to the operating table. The probe has been placed at the height of the respiratory tract of the OR staff, closest to the SED. The multi-gas monitor (model 1302 Brüel and Kjaer) was a portable infrared photoacoustic spectroscopy automatic analyzer able to perform in real time an air sampling of the OR. The multi-gas monitor was programmed to perform every 2 minutes the intake of an air sample (.14 L).

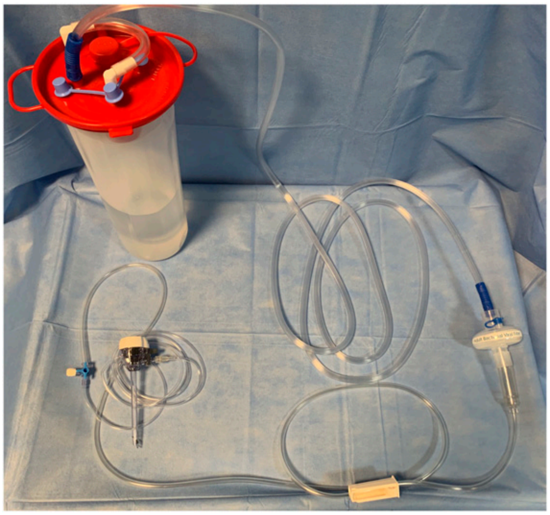

Figure 1. Homemade device for smoke evacuation.

Quantitative analysis of CO_2 environmental dispersion, expressed in parts per million (ppm), was carried out in the empty OR ("at rest condition") and during the procedure ("operational conditions") in the presence of patient and exposed staff (8÷10 operators).[9,10]

The analysis has been carried out into two OR of University Federico II of Naples. The characteristics of OR and air flow systems are illustrated in Table 1.

In order to evaluate the pneumoperitoneum stability, for each surgical procedure we also collected: a preset insufflation pressure (IP), real intraoperative pneumoperitoneum pressure (RIP) with a data recording every 15 minutes, operative time, total volume of insufflated CO_2, and flow rate index.

In all groups, pneumoperitoneum was always carried out with open Veress-assisted technique,[10] instead of open Hasson technique, in order to reduce the risk of gas leakage at the skin trocar site.[4]

At the end of the surgery, a well-controlled wall-suction of the intra-abdominal CO_2 was performed. Statistical analysis was performed with SPSS version 22.0 statistic software package (IBM-SPSS Inc, Chicago, IL, USA). Data were expressed as means ± standard deviation (SD). A value of $P < .05$ was considered statistically significant.

Results

A total of 16 patients (4 for each group) underwent laparoscopic surgery for oncological diseases. OR setting data and procedural results are described in Table 2.

Table 1. OR characteristics.

Operation room				Air flow system					
					Input air			Output air	
Name	Dimension (m)	Area (m^2)	Volume (m^3)	Type	N. Unit air diffusers	Area (m^2 $unit^{-1}$)	VCCC [2] air input (m^3/h)	N. Unit air diffusers	Area (m^2 $unit^{-1}$)
OR "A"	7.10 (L) × 5.23 (W) x 2.90 (H)	37	108	TMA[1]	4	0.4	2361	8	0.2
OR "B"	6.00 (L) × 5.40 (W) x 2.90 (H)	32	94	TMA[1]	4	0.4	2073	8	0.2

[1]TMA: turbulent mixed airflow.
[2]VCCC: controlled contamination ventilation and air conditioning.
Abbreviation: OR = operating room.

Table 2. Surgical data.

Patient	Surgical procedure	Operative time (min)	Volume of CO_2 (L)	Flow rate (L/min)	IP (mmHg)	RIP (mmHg)	Personnel (n)
S1 group: AIRSEAL® system							
1	Right colectomy	140	420	3	11	10	9
2	Left colectomy	160	565	3.5	11	10	10
3	Rectum anterior resection	200	630	3.1	11	10	10
4	Pancreaticoduodenectomy	240	744	3.1	11	10	9
	Mean	185	589.7	3.2	11	10	9.5
S2 group: Homemade device							
5	Left colectomy	155	760	4.9	12	9	10
6	Subtotal gastrectomy	250	1350	5.4	12	10	9
7	Rectum anterior resection	180	607	3.4	12	10	9
8	Pancreaticoduodenectomy	230	1288	5.6	12	9	9
	Mean	203.7	1001.2	4.8	12	9.5	9.25
S3 group: AIRSEAL® system + homemade device							
9	Hepatic metastasectomy	54	372	6.8	10	8	8
10	Right colectomy	152	430	2.8	12	10	9
11	Left colectomy	150	557	3.7	12	10	8
12	Rectum anterior resection	200	720	3.6	12	9	9
	Mean	139	519.7	4.2	11.5	9.2	8.5
S4 group: No device							
13	Subtotal gastrectomy	260	1638	6.3	12	10.8	10
14	Left colectomy	150	780	5.2	12	11	9
15	Rectum anterior resection	190	931	4.9	12	10.2	10
16	Right colectomy	130	520	4	12	10	8
	Mean	182.5	967.2	5.1	12	10.5	9.25

Abbreviations: IP = insufflation pressure; RIP = real intraoperative pneumoperitoneum pressure.

Results of CO_2 monitoring in the OR (average, standard deviation and range of ppm) are reported in Table 3.

The trend of CO_2 concentration using the AIRSEAL® system showed that the environmental dispersion of CO_2 had peaks of 972 ppm, 930 ppm, 985 ppm, and 883 ppm, respectively.

The environmental concentration of CO_2 using the homemade device demonstrated peaks of 795 ppm, 813 ppm, 836 ppm, and 819 ppm, respectively. The environmental concentration of CO_2 using AIRSEAL® system + homemade device had peaks of 765 ppm, 772 ppm, 766 ppm, and 749 ppm, respectively. Finally, the environmental concentration of CO_2 using standard trocars had peaks of 1217 ppm, 1146 ppm, 1024 ppm, and 992 ppm, respectively (Table 3 and Figure 2).

For each group, we report a box plot analysis (Figure 3) of CO_2 concentrations comparison. In the S1 group, CO_2 mean value was 711 ppm (median 741 ppm and range of

Table 3. OR CO_2 concentration measured with different evacuation systems.

Patient	S1 group: AIRSEAL® system Mean ± standard deviation	Range	S2 group: Homemade device Mean ± standard deviation	Range	S3 group: AIRSEAL® system + homemade device Mean ± standard deviation	Range	S4 group: No device Mean ± standard deviation	Range
1	700 ± 171	421÷972	640 ± 117	405÷795	575 ± 100	427÷765	845 ± 306	429÷1217
2	713 ± 193	415÷930	654 ± 143	435÷813	603 ± 125	408÷772	828 ± 298	435÷1146
3	721 ± 187	418÷985	629 ± 166	441÷836	600 ± 116	433÷766	715 ± 256	419÷1024
4	709 ± 160	420÷883	653 ± 124	420÷819	595 ± 111	418÷749	686 ± 249	419÷992
	Mean value 711 ppm		Mean value 641 ppm		Mean value 593 ppm		Mean value 761 ppm	

Abbreviation: ppm: *parts per million*.

415÷985 ppm); in the S2 group, mean value was 641 ppm (median 652 ppm and range of 405÷836 ppm); in the S3 group, mean value was 593 ppm (median 598 ppm and range of 408÷772 ppm); and in the S4 group, mean value was 761 ppm (median 762 ppm and range of 419÷1217 ppm). The comparison between data showed statistically significant differences about the measured ambient CO_2 concentration among all groups (P-value < 0.01). Finally, AIRSEAL® system alone or in combination with a homemade device seems to provide a more stable pneumoperitoneum respect to the other SEDs (Table 2).

Discussion

Since the beginning of the COVID-19 era, a lot of elective surgeries are being canceled, and during the pandemic peak, only emergency or oncological procedures are performed.[11,12] Almost immediately, the UK and Ireland Intercollegiate Board stated that "laparoscopy is considered to carry some risks of aerosol-type formation and infection and considerable caution is advised"[13] Immediately after, SAGES and EAES stated that although some research studies have been reported that laparoscopy can lead to aerosolization of blood-borne viruses, there is no evidence to indicate that this effect is seen with COVID-19 nor that it would be isolated to minimally invasive surgical procedures.[6] So they suggested to limit the use of the most common energy devices due to the produced amounts of surgical smoke, and they recommended the use of SED with CO_2 filtering systems as one of the most useful precautions to reduce the potential risk of viral transmission through the surgical smoke.

Therefore, we thought to evaluate the efficacy of some different SEDs comparing one with the other and with a standard trocar setting. In order to investigate the capacity of smoke evacuation maintaining a stable pneumoperitoneum, we analyzed some parameters as the quantitative analysis of CO_2 environmental dispersion combined with other parameters as the RIP, the total volume of insufflated CO_2, and the flow rate index.

Our results suggested that the use of AIRSEAL® system alone despite providing a more stable pneumoperitoneum than an homemade SED showed a higher environmental dispersion of CO_2; probably a leakage of unfiltered CO_2 could be caused by the surgical instruments exchange and manipulation through the standard trocars. Conversely, the homemade SED[7] seems to be a low-cost, safe, and effective method for smoke evacuation but with a less capacity to provide a stable pneumoperitoneum. This means a higher volume of insufflated CO_2 which is in contrast with the recent international recommendations.[6] So, we decided to test both SEDs together as suggested by the SAGES-EAES Guidelines.[6]

In the S3 group, the RIP stability guaranteed by the *AIRSEAL® system* combined with the greater capability of smoke evacuation of the homemade device has resulted as the best solution as shown in Figures 2 and 3.

However, all the aforementioned devices allow to not exceed the recommended threshold limit value—time weighted average (T.L.V.-T.W.A.) of 5000 ppm and the threshold limit value—short-term exposure limit (T.L.V. - S.T.E.L.) of 30 000 ppm for CO_2 suggested by the American Conference of Governmental Industrial Hygienists (A.C.G.I.H.).[9,14]

More generally, the problem of an adequate smoke evacuation during surgical procedures, especially those laparoscopic, does not concern only the risk of viral transmission as the SARS-CoV-2.

The American Occupational Safety and Health Administration (OSHA) estimates that 500.000 workers are exposed to electrosurgical smoke each year, including surgeons, nurses, and anesthesiologists. Various studies demonstrated that specially designed masks (respirators) are still insufficient barriers. The OSHA does not specifically require the use of smoke evacuation and filtering systems. Instead, other organizations recommend smoke evacuation systems where high concentrations of smoke

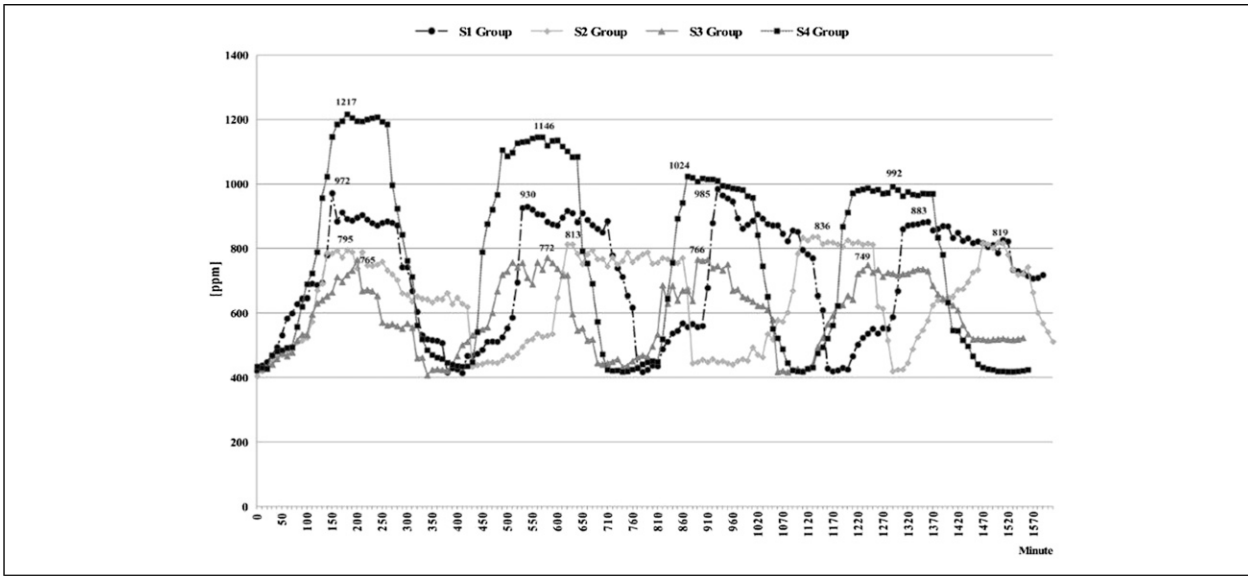

Figure 2. *Trend of CO_2 concentration in the 4 different groups.*

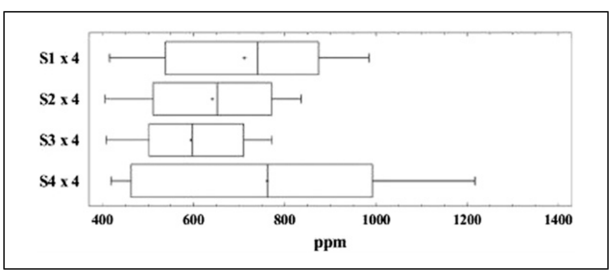

Figure 3. *Comparison of CO_2 concentration in the 4 different groups.*

and aerosols are generated. During laparoscopic procedures, the use of SEDs could be more strongly recommended because smoke is accumulated and then released all at once in a relatively high-velocity jet. Consequently, the surgeon or OR personnel can be exposed to a high concentration as demonstrated by Choi et al.[9] Similarly, the study of Li et al demonstrates that the particle concentration of the smoke after ten minutes using electrical or ultrasound devices in laparoscopic surgery is higher than in open surgery. Moreover, surgical smoke has been demonstrated to be cytotoxic, genotoxic, and mutagenic. In fact, while hydrocarbons, phenols, nitriles, and fatty acids are the most prominent chemicals found in electrocautery smoke, acrylonitrile and carbon monoxide (CO) are of most concern. Short-term exposure can cause eye irritation, nausea, vomiting, headache, sneezing, weakness and lightheadedness. Long-term exposure could cause cancer.[2] So, regardless to the risk of viral transmission during COVID-19, the use of effective smoke evacuation systems during surgical procedures seems to be a concern of huge relevance.

A recent study reported that there are several factors influencing the particulate removal capability of smoke evacuator as the efficiency and size of their filters, the minimum flow rate, the ability to vary both the flow rate and noise level (ideally below 60 dB), ergonomic features, portability, cost-effectiveness, and ease of maintenance.[15] However, the ideal SED for laparoscopic surgery should merge the smoke removal capability to the maintenance of a stable pneumoperitoneum, avoiding slowing down the surgical procedure. The majority of the currently available smoke evacuation devices try to merge both these capabilities. They used a triple-filter system, which includes a prefilter that captures large particles, a ULPA filter, and a special charcoal that captures the toxic chemicals found in smoke. Unfortunately, the trocar represents a point of weakness, allowing the inadvertent release of CO_2 determining also an instability of the pneumoperitoneum. Our study has some limitations as different oncologic procedures with different pneumoperitoneum pressures and number of placed trocars. So this could affect the results. Moreover, other SEDs are commercially available, and future studies should compare their efficacy with each other.

Conclusion

All tested SEDs seem to be useful to reduce the CO_2 environmental dispersion respect to a standard trocar setting. However, the association of *AIRSEAL® system* and homemade device seems to be the best solution combining an adequate smoke evacuation and a stable pneumoperitoneum during laparoscopic surgery.

Regardless of the COVID-19 era, an adequate smoke evacuation represents the great challenge for mini-invasive surgeons, trying to break down environmental dispersion and reducing the potential biological risk and impact on the indoor air quality. Despite recommendations from many international surgical societies advocating the use of smoke extraction devices in operating rooms, these devices are still too little employed.

Acknowledgments

We thank Juliet Ippolito, BA. Vassar College, MPhil University of Dundee for English language editing.

Author Contributions

Study concept and design: Umberto Bracale, Giovanni Merola, Francesco Corcione, and Maria Triassi.
Acquisition of data: Vania Silvestri, Emanuele Pontecorvi, Paolo Montuori, and Immacolata Russo.
Analysis and interpretation: Giovanni Merola, Umberto Bracale, Luigi Boni, and Elisa Cassinotti.
Study supervision: Umberto Bracale, Francesco Corcione, and Maria Triassi.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Umberto Bracale https://orcid.org/0000-0002-9868-0889

References

1. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med*. 2020;382(8):727-733. doi:10.1056/NEJMoa2001017.
2. Alp E, Bijl D, Bleichrodt RP, Hansson B, Voss A. Surgical smoke and infection control. *J Hosp Infect*. 2006;62(1):1-5. doi:10.1016/j.jhin.2005.01.014.
3. Kwak HD, Kim S-H, Seo YS, Song K-J. Detecting hepatitis B virus in surgical smoke emitted during laparoscopic surgery. *Occup Environ Med*. 2016;73(12):857-863. doi:10.1136/oemed-2016-103724.
4. Mowbray NG, Ansell J, Horwood J, et al. Safe management of surgical smoke in the age of COVID-19. *Br J Surg*. 2020;107:1406-1413. doi:10.1002/bjs.11679.
5. Choi SH, Kwon TG, Chung SK, Kim T-H. Surgical smoke may be a biohazard to surgeons performing laparoscopic surgery. *Surg Endosc*. 2014;28(8):2374-2380. doi:10.1007/s00464-014-3472-3.
6. Francis N, Dort J, Cho E, et al. SAGES and EAES recommendations for minimally invasive surgery during COVID-19 pandemic. *Surg Endosc*. 2020;34(6):2327-2331. doi:10.1007/s00464-020-07565-w.
7. Mintz Y, Arezzo A, Boni L, Chand M, Brodie R, Fingerhut A. A low-cost, safe, and effective method for smoke evacuation in laparoscopic surgery for suspected coronavirus patients. *Ann Surg*. 2020;272(1):e7-e8. doi:10.1097/SLA.0000000000003965.
8. SAGES. *Resources for smoke & gas evacuation during open, laparoscopic, and endoscopic procedures. SAGES*. 2020. https://www.sages.org/resources-smoke-gas-evacuation-during-open-laparoscopic-endoscopic-procedures/.March 29
9. Choi DH, Choi SH, Kang DH. Influence of surgical smoke on indoor air quality in hospital operating rooms. *Aerosol and Air Quality Research*. 2017;17:821-830. doi:10.4209/aaqr.2016.05.0191.
10. Bracale U, Azioni G, Rosati M, Barone M, Pignata G. Deep pelvic endometriosis (Adamyan IV stage): Multidisciplinary laparoscopic treatments. *Acta Chir Iugosl*. 2009;56:41-46. doi:10.2298/aci0901041b.
11. Zheng MH, Boni L, Fingerhut A. Minimally invasive surgery and the novel coronavirus outbreak: Lessons learned in China and Italy. *Ann Surg*. 2020;272:e5-e6. doi:10.1097/SLA.0000000000003924.
12. Bracale U, Podda M, Podda M, et al., CLOUD-19 Collaborative Group. Changes in surgical behaviors during the COVID-19 pandemic. The SICE CLOUD19 study. *Updates in Surgery*. 2021;73:731-744. doi:10.1007/s13304-021-01010-w.
13. TRCoSo E. Intercollegiate general surgery guidance on COVID-19 UPDATE. *The Royal College of Surgeons of Edinburgh*. March 27 2020. https://www.rcsed.ac.uk/news-public-affairs/news/2020/march/intercollegiate-general-surgery-guidance-on-covid-19-update
14. American Conference of Governmental Industrial Hygienists (A.C.G.I.H.). *2017 TLVS and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists;2017.
15. Li C-II, Pai C-H, Chen CH. Characterization of smoke generated during the use of surgical knife in laparotomy surgeries. *J Air Waste Manag Assoc*. 2020;70:324-332. doi:10.1080/10962247.2020.1717675.