Research Repository UCD

Title	Aerosols, airflow, and airspace contamination during laparoscopy
Authors(s)	Hardy, Niall, Dalli, Jeffrey, Khan, Mohammad Faraz, Nolan, Kevin Patrick, Cahill, Ronan
Publication date	2021-09-27
Publication information	Hardy, Niall, Jeffrey Dalli, Mohammad Faraz Khan, Kevin Patrick Nolan, and Ronan Cahill. "Aerosols, Airflow, and Airspace Contamination during Laparoscopy." Oxford University Press, September 27, 2021. https://doi.org/10.1093/bjs/znab114.
Publisher	Oxford University Press
Item record/more information	http://hdl.handle.net/10197/13093
Publisher's version (DOI)	10.1093/bjs/znab114

Downloaded 2026-05-01 23:36:17

The UCD community has made this article openly available. Please share how this access benefits you. Your story matters! (@ucd_oa)

© Some rights reserved. For more information

OXFORD

BJS, 2021, 1–4
DOI: 10.1093/bjs/znab114
Rapid Research Communication

Aerosols, airflow, and airspace contamination during laparoscopy

N. Hardy [1], J. Dalli [1], M. F. Khan[1], K. Nolan[2] and R. A. Cahill [1,3,*]

[1]UCD Centre of Precision Surgery, School of Medicine, University College Dublin, Dublin, Ireland
[2]School of Mechanical and Material Engineering, University College Dublin, Dublin, Ireland
[3]Department of Surgery, Mater Misericordiae University Hospital, Dublin, Ireland

*Correspondence to: UCD Centre of Precision Surgery, School of Medicine, University College Dublin, 47 Eccles Street, Dublin 7, Ireland (e-mail: ronan.cahill@ucd.ie)

Lay summary

Laparoscopic surgery has been undermined throughout the COVID-19 pandemic by concerns that it may generate an infectious risk to the operating team through aerosolization of peritoneal particles. There is anyway a need for increased awareness and understanding of the occupational hazard for surgical teams regarding unfiltered escape of pollutants generated by surgical smoke and other microbials. Here, the aerosol-generating nature of this access modality was confirmed through repeatable real-time methodology both qualitatively and quantitively to inform best practice and additional engineering solutions to optimize the operating room environment.

Introduction

The COVID-19 pandemic has focused attention on the infectious transmission risk of laparoscopy for operating room (OR) staff[1,2]. In addition, there needs to be increased understanding of the potential dangers from surgical smoke pollution in surgical theatres despite positive-pressure room ventilation; this issue is now being prioritized by the Joint Commission[3] among other groups[4,5]. Better empirical understanding of aerosols, airflow impact, and airspace contamination of laparoscopy would inform best practice as well as its appropriateness for classification among aerosol-generating procedures, while promoting and inspiring methods for hazard mitigation. Here, the methodology for such advancement is described, along with early findings from such evaluations including during surgery[6,7].

Methods

With institutional ethics approval (AEROSOLVE study, institutional review board reference 1/378/2172) and individual participant consent (from both OR team members and, when involved, patients), flow visualization studies were performed in the OR before and during elective laparoscopic operations. First, formal smoke studies were used to detail room ventilation dynamics around the operating table during surgical simulation scenarios with and without positive-pressure room ventilation (25 room air exchanges per h). For this, an Air-Trace smoke generator (Concept Engineering, Maidenhead, UK) created low levels of isokinetic, isothermal smoke via a 25-mm duct. The scenarios replicated personnel and equipment conditions for surgical procedures with varying complexity of set-up (open inguinal hernia repair, laparotomy, laparoscopic appendicectomy, laparoscopic cholecystectomy, and laparoscopic anterior resection) with the smoke generator hose positioned at the simulated operative site.

Thereafter, flow studies were performed during actual elective operations with varying degrees of intraoperative electrocautery (6 procedures; 3 laparoscopic cholecystectomies, 2 laparoscopic appendicectomies, 1 laparoscopic parastomal hernia repair; standard pneumoperitoneal pressure setting 12 mmHg). For this, a light sheet generated by a galvanometer optical laser scanner was used to illuminate a two-dimensional (2D) slice of the surgical airspace during surgery and imaged with an 8 K Ultra-High Definition camera (Canon EOS R5 with RF 35 mm f/1.8 lens; Canon, Ohta-ku, Tokyo, Japan) whose absence of diffraction limitation enabled resolution of droplets larger than 2 μm (visible as scintillations within the laser sheet). Simultaneous extracorporeal airspace sampling was performed during these operations after investigator training using a particle counter (model 8306; Particles Plus, Stoughton, Massachusetts, USA) to measure 30-s periods both at baseline (before surgical incision) and then episodically during the procedure by positioning the device's isokinetic probe inlet 10 cm from the target area[8]. This device cumulatively measures particles by laser diode with differential counting (0.3–25 μm) at 0.1 Cubic Feet per Minute flow (2.83 Litres per Minute).

Results

Smoke studies revealed effective dissipation of smoke by positive-pressure room ventilation with the OR fully empty, as expected. However, during simulated operative scenarios, smoke behaviour was significantly different, with evident upwards drift

Received: January 15, 2021. **Revised:** February 15, 2021. **Accepted:** March 01, 2021
© The Author(s) 2021. Published by Oxford University Press on behalf of BJS Society Ltd. All rights reserved.
For permissions, please email: journals.permissions@oup.com

from the operating site enveloping members of the surgical team (*Video S1* and *Appendix S1*). Increased crowding of the operating table with people and equipment caused increased local air stagnation. Intraoperative footage during patient operations showed smoke and particles (evidenced as scintillations) moving similarly during surgery, notable even with the instruments *in situ*, as well as during manoeuvres including trocar instrumentation, and venting and specimen removal (*Fig. 1* and *Video S1*). Aerosol and particle leakage into the OR airspace was most evident during the operative phase of intra-abdominal dissection using hook cautery.

Particle counts confirmed increasing particulate concentration after initiation of the operation, reaching extracorporeal airspace levels in excess of 1×10^6 particles per m^3, the majority being 0.3–0.5 μm and, during cholecystectomy, 5–10 μm (*Table 1*). Counts were particularly increased during electrocautery dissection of the gallbladder from the liver bed during cholecystectomy compared with dissection of the mesoappendix during appendicectomy, which in turn was associated with higher counts than were observed during intra-abdominal reduction of a parastomal hernia (done without cautery dissection). Trocar venting caused the highest concentration of particulate effluvium.

Discussion

This study focused on establishing methods and indicative data regarding the operative airspace particulate contamination occurring during laparoscopy, using open procedures as control in a simulation study as well as in two common general surgical laparoscopic operations that employ electrocautery to different extents (versus a laparoscopic operation without electrocautery). This is important as many surgical teams feel any such occupational hazard to be either theoretical or mitigated anyway by room ventilation and perhaps standard surgical masks[9]. However, OR ventilation standards and indeed commissioning assume that empty theatres and surgical masks protect only primarily against large fluid droplet inhalation (and are loose fitting).

The evaluations in this study reflect actual workspace conditions of OR teams, corroborating simulation data with live intraoperative flow visualization and sensitive particle counting (necessary as the laser sheet provides only a 2D slice and so underestimates total particle concentration). Together, these show that the surgical team is exposed to considerable amounts of particles and pollutants during laparoscopy. Indeed, aerosol (containing gas and particles) leaks continuously from the patient during laparoscopic operations, with such flue comprising the constituents of the pneumoperitoneal gas including any noxious components present. The local OR airspace pollution is particularly marked during the cautery dissection phase of the operation, and occurs constantly rather than just at the time of instrument insertion and removal[10]. Particle counts increase during the operation even without cautery and trocar venting causes the greatest effluvium stream. A substantial proportion of the aerosolized particles are less than 5 μm in size and so may remain airborne indefinitely unless removed[11]. All airborne particles smaller than 10 μm can be inhaled, with those greater than 2.5 μm depositing within the nose, pharynx, trachea, and bronchi, whereas smaller particles reach the bronchioles and alveoli where those smaller than 0.1 μm are absorbed into the circulatory system[9] .The smoke simulation studies show that modern OR positive-pressure ventilation sufficient to meet official requirements (https://www.gov.uk/government/collections/health-technical-memorandum-disinfection-and-sterilization) is not powerful enough to counteract the local airspace environment created by surgical teams carrying out their work. This

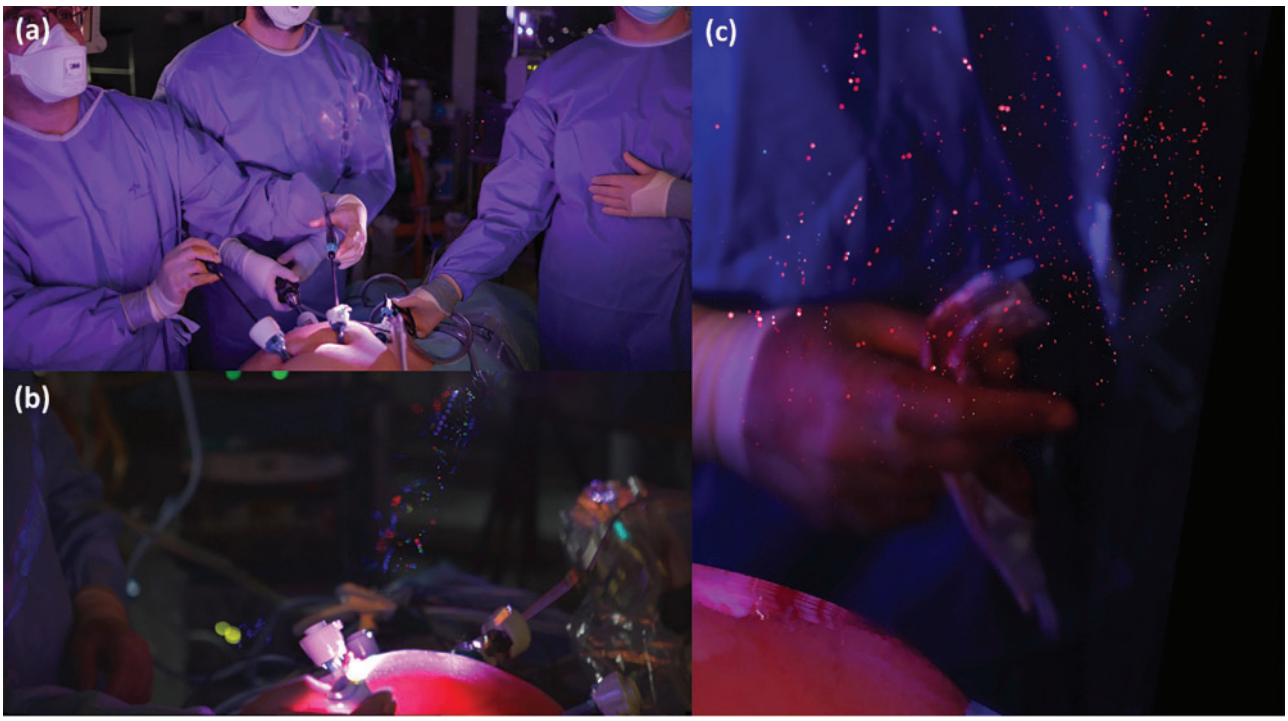

Fig. 1 Comet plot images (maximum-averaged stack of sequential 12-bit Raw frames of intraoperative footage) showing particles including trajectories as repeated particle groups in the operative airspace during (a) dissection of the gallbladder from the liver bed during cholecystectomy (b) with the laparoscopic port luer lock open to vent intrabdominal smoke and (c) on specimen extraction via a periumbilical incision (imagery best appreciated by viewing the associated video).

Accompanying *Video S1* is available online showing flow visualization studies for both particles and gas during surgery and smoke for operating room ventilation assessment during simulations.

Table 1 Mean extracorporeal airspace particle counts during operations

Operative phase	Total no. of particles	Particle count by size					
		0.3 μm	0.5 μm	1.0 μm	2.5 μm	5 μm	10 μm
Laparoscopically assisted parastomal hernia repair (*n* = 1)							
Background before incision	126 188	60 505 (1)	33 901 (1)	9888 (1)	14 361 (1)	3295 (1)	4237 (1)
Intraoperative	120 538	68 510 (1)	36 962 (1)	3766 (0)	5650 (0)	1883 (1)	3766 (1)
Intraoperative, trocar venting (5-mm port)	289 225	130 311 (2)	73 807 (2)	30 724 (3)	31 077 (2)	13 066 (4)	10 241 (2)
Laparoscopic appendicectomy (*n* = 2)							
Background before incision	423 420	184 813 (1)	112 771 (1)	61 565 (1)	41 789 (1)	10 006 (1)	12 477 (1)
Intraoperative, before dissection	1 068 619	421 657 (2)	307 943 (3)	180 811 (3)	108 062 (3)	29 664 (3)	20 482 (2)
Intraoperative, during dissection	1 805 989	1 689 100 (9)	81 223 (1)	20 835 (0)	12 007 (0)	1059 (0)	1766 (0)
Laparoscopic cholecystectomy (*n* = 3)							
Background before incision	151 536	39 729 (1)	57 563 (1)	27 545 (1)	22 072 (1)	4307 (1)	322 (1)
Intraoperative, during dissection	776 358	300 528 (8)	11 830 (0)	2472 (0)	4414 (0)	420 139 (98)	36 977 (115)
Intraoperetive, trocar venting during dissection	9 271 468	8 289 764 (208)	127 839 (2)	5650 (0)	2118 (0)	674 726 (157)	171 371 (532)

Values in parentheses are ratio of counts in operative phase to background counts (BKD, counts after patient positioning, preparation, and draping but before incision). Dissection during appendicectomy and cholecystectomy was performed using hook monopolar point diathermy.

means that there is relative stagnation of haze in the operative airspace above the abdomen during laparoscopic operation, with entrainment towards surgical team members likely induced by movement, body heat, and electrostaticity[12].

Although investigation of COVID-19 infectivity owing to laparoscopic access is ongoing, the pandemic has already caused considerable reflection regarding the aerosol-generating capability of laparoscopy, and encouraged re-examination of practice and equipment from this new perspective[13,14]. Most attention has focused on surgical smoke extraction[15,16], although to date most recommendations have been based on theoretical extrapolations[17,18] from expert groups and industry without independent, empirical data to guide evolved thinking and practice regarding laparoscopic care[19]. Importantly, the pandemic has also educated, equipped, and enabled familiarity of OR teams with better respiratory protection (such as N95/FFP2/FFP3 masks) and smoke extraction principles and systems, including laparoscopic devices. The opportunity therefore presents to continue to protect surgical personnel in both these terms and others (including considering OR redesign). Further work is of course needed to expand this work to additional operations (including more major resectional operations of longer duration, greater energy device use, and larger-diameter instrumentation, including trocars and staplers, which likely exacerbate the levels of airspace contamination[10]) and indeed other surgical specialties.

The implications of the present study regarding aerosolization at laparoscopy extend beyond the present pandemic. The results provide insight into both mechanism and degree as well as assessment methodology for future evaluations, including those of mitigation strategies. Although practice advice[1] and personal protective equipment[20] have a positive impact, there should also be much confidence that improved awareness and smart engineering innovations can ameliorate current laparoscopic access equipment and environmental standards, ensuring better occupational hygiene for OR teams.

Acknowledgements

The authors thank M. Kelly (Mater Misericordiae University Hospital Estates Department) and S. Ryan (Spectrum Environmental, Dublin, Ireland) for their expertise in OR ventilation systems and smoke study assessments; and M. Maher (Image Supply Systems, Dublin, Ireland) and Canon Ireland for their expertise and provision of a Canon EOS R5 camera for the purposes of this study. R.A.C. and K.N. have received funding from EU Horizon 2020 for a research programme in Protecting Operating Room Staff Against Viruses (PORSAV) as part of a consortium including Palliare (Ireland), Steripak (Poland), and IRCAD/EITS (France) since the completion of this unfunded work. R.A.C. has also received speaker fees from Ethicon Johnson & Johnson in this area. Separately, for unrelated work, R.A.C. has received speaker fees from Stryker, consultancy fees from Distal Motion and Touch Surgery, and holds research funding from Medtronic, Intuitive Corporation and from the Irish Government with IBM Research and Deciphex, Ireland.

Disclosure. The authors declare no other conflict of interest.

Supplementary material

Supplementary material is available at *BJS* online.

References

1. Francis N, Dort J, Cho E, Feldman L, Keller D, Lim R *et al.* SAGES and EAES recommendations for minimally invasive surgery during COVID-19 pandemic. *Surg Endosc* 2020;**34**: 2327–2331
2. Allan M, Mahawar K, Blackwell S, Catena F, Chand M, Dames N *et al.* PRODUCE study. COVID-19 research priorities in surgery (PRODUCE study): a modified Delphi process. *Br J Surg* 2020;**107**: e538–e540
3. The Joint Commission. *Quick Safety Issue 56: Alleviating the Dangers of Surgcial Smoke.* https://www.jointcommission.org/resources/news-and-multimedia/newsletters/newsletters/quick-safety/quick-safety-issue-56/ (accessed 15 January 2020)
4. Schultz L. An analysis of surgical smoke plume components, capture & evacuation. *AORN J* 2014;**99**:289–298
5. Vortman R, McPherson S, Wendler C. State of the Science: a concept analysis of surgical smoke. *AORN J* 2021;**113**:41–51
6. Cahill RA, Dalli J, Khan M, Flood M, Nolan K. Solving the problems of gas leakage at laparoscopy. *Br J Surg* 2020;**107**: 1401–1405
7. Uecker JM, Fagerberg A, Ahmad N, Cohen A, Gilkey M, Alembeigi F *et al.* Stop the leak! Mitigating potential exposure of

aerosolized COVID-19 during laparoscopic surgery. *Surg Endosc* 2021;**35**:493–501
8. Dalli J, Hardy N, Khan MF, Cahill RA. Bioaerosols during transanal minimally invasive surgery. *Lancet Respir Med* 2020;**8**:914–924
9. Limchantra IV, Fong Y, Melstrom KA. Surgical smoke exposure in operating room personnel: a review. *JAMA Surg* 2019;**154**: 960–967
10. Khan MF, Dalli J, Cahill RA. Gas aerosol jetstreams from trocars during laparoscopic surgery—a video vignette. *Colorectal Dis* 2020;**22**:1028–1029
11. Fennelly KP. Particle sizes of infectious aerosols: implications for infection control. *Lancet Resp Med* 2020;**8**:914–924
12. Bhagat RK, Davies Wykes MS, Dalziel SB, Linden PF. Effects of ventilation on the indoor spread of COVID-19. *J Fluid Mech* 2020; **903**:F1
13. Dalli J, Khan MF, Nolan K, Cahill RA. Laparoscopic pneumoperitoneum escape and contamination during surgery using the Airseal Insufflation System—a video vignette. *Colorectal Dis* 2020;**22**:1029–1030
14. Hamed H. Underwater-seal evacuation of surgical smoke in laparoscopy during the COVID-19 pandemic: a feasibility report of a simple technique. *Br J Surg* 2020;**107**:e640–e641
15. Campanile FC, Campanile LF. Smoke evacuation filters after the COVID-19 pandemic: technical awareness for safety. *Ann Surg* 2020;**272**:e266–e268
16. Mowbray NG, Ansell J, Horwood J, Cornish J, Rizkallah P, Parker A *et al.* Safe management of surgical smoke in the age of COVID-19. *Br J Surg* 2020;**107**:1406–1413
17. Zakka K, Erridge S, Chidambaram S, Beatty JW, Kynoch M, Kinross J *et al.*; PanSurg collaborative group. Electrocautery, diathermy, and surgical energy devices: are surgical teams at risk during the COVID-19 pandemic? *Ann Surg* 2020;**272**: e257–e262
18. Chadi SA, Guidolin K, Caycedo-Marulanda A, Sharkawy A, Spinelli A, Quereshy FA *et al.* Current evidence for minimally invasive surgery during the COVID-19 pandemic and risk mitigation strategies: a narrative review. *Ann Surg* 2020;**272**: e118–e124
19. Dalli J, Khan MF, Nolan K, Cahill RA. Canaries in the mine. *Br J Surg* 2021;**108**:e69–e70. doi: 10.1093/bjs/znaa065
20. Stewart CL, Thornblade LW, Diamond DJ, Fong Y, Melstrom LG. Personal protective equipment and COVID-19: a review for surgeons. *Ann Surg* 2020;**272**:e132–e138