

ORIGINAL RESEARCH

Quantification and visualization of aerosols in ear, nose, and throat exam and flexible laryngoscopy

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Abstract

Objective: To measure and visualize aerosol generation during ear, nose, and throat (ENT) exam and flexible laryngoscopy, as safety recommendations are currently to defer routine and low-priority examinations.

Methods: Aerosols generated during ENT examination and flexible laryngoscopy were quantified by laser aerosol spectrometry and visualized live by high-speed imaging during those procedures for three participants who were tested three times for each test.

Results: Routine ENT examination and flexible laryngoscopy produce aerosols at levels comparable to normal breathing and speech.

Conclusion: During ENT examination and flexible laryngoscopy, the practitioner should wear a surgical mask and potentially contaminated surfaces should be cleaned after the procedure. For flexible laryngoscopy, it is recommended in addition that the patient wear a mask over the mouth in case the procedure induces a sneeze. The time during which the patient is unmasked should be minimized. In these settings, the risk to the practitioner is minimal unless the patient is sneezing or symptomatic.

Level of Evidence: 1

KEYWORDS

aerosols, COVID-19, ENT examination, flexible laryngoscopy, safety

1 | INTRODUCTION

Human to human transmission of SARS-CoV-2 has been confirmed through both asymptomatic and presymptomatic transmission¹⁻⁴; reports suggest that up to 40%–45% of SARS-CoV-2 infections occur without symptoms.⁵ Health care workers are especially at risk during

the COVID-19 pandemic.^{6,7} While SARS-CoV-2 is mainly present in the lower respiratory tract, virus shedding in the nasopharynx and oropharynx is also observed.⁸⁻¹¹ This is highly concerning for aerosol-generating procedures as SARS-CoV-2 viral particles can remain viable in aerosols for 3 h.¹²

Since oral fluid droplets can be generated during speech,¹³ universal masking in clinical settings is now widely accepted as a measure to reduce transmission.^{14,15} However, many clinical procedures require lowering or removal of the patient's mask. In this study, we

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focused on routine ear, nose, and throat (ENT) examinations and flexible laryngoscopy, procedures for which the patient's mask must be either lowered or removed. The current safety recommendations for ENT examination and flexible laryngoscopy are to defer routine and low-priority examinations as long as there is active community transmission of COVID-19.¹⁶ Although head and neck physical examinations are not typically classified as aerosol-generating procedures, there is a lack of knowledge on the dynamics of aerosol generation during ENT exam.¹⁷ For flexible laryngoscopy, evaluation of aerosol and droplets generation have been attempted; one study concluded that this was not an aerosol-generating procedure,¹⁸ while another concluded that the procedure poses a minimal droplet risk,¹⁹ and a more recent one measured aerosols in the whole clinic room and concluded there were no additional particle aerosolization.²⁰ This study fills the current knowledge gap for aerosol generation during ENT exam and also visualize precisely aerosol generation during scope removal during flexible laryngoscopy. Furthermore, patients may frequently cough or sneeze during ENT examination and flexible laryngoscopy. This was not evaluated in previous studies.

The aim of this study was to accurately quantify aerosols generated during ENT examination, flexible laryngoscopy, coughing, and sneezing and to assess recommendations for safe realization of those procedures in the context of the COVID-19 pandemic. Despite the advent of vaccines, the number of unvaccinated people in even developed countries indicates that herd immunity will not be attained in the near future. The situation is worse in less wealthy countries that rely on vaccine distribution through the COVAX initiative. Furthermore, one of the major lessons learned during the COVID-19 pandemic was that health care systems were not adequately prepared to fight a worldwide pandemic. A better understanding of aerosol generation during common clinical manipulations along with the development of new clinical guidelines to reduce risk and transmission will increase preparedness for potential future pandemics.

2 | MATERIALS AND METHODS

2.1 | Study design

Three healthy male participants aged 37–45 years old were recruited at the Centre Hospitalier de l'Université de Montréal, and informed consent was obtained in accordance with the research protocol (#20.104) approved by the institutional review board. Participants had no COVID-19 symptoms and no recent history of COVID-19 contact. Measurements were performed in the multiphase and reactive flows laboratory of Dr. Étienne Robert at Polytechnique Montréal by a multidisciplinary team of otolaryngologists and engineers. The room ventilation was idle and room temperature was maintained at 22°C. The experiment was conducted in two parts. First, we quantified small aerosol particles produced during normal breathing, talking, ENT examination, flexible laryngoscopy, coughing, and

sneezing. Second, we visualized aerosol particles with high-speed laser illumination and counted larger particles produced during flexible laryngoscopy, coughing, and sneezing.

2.2 | Aerosol spectrometry

A laser aerosol spectrometer (LAS) (GRIMM 11-R, Grimm, Germany) was used to determine the size distribution and number of aerosol particles produced by the participant. The LAS samples aerosols and measures particles between 0.25 and 32 μm in 31 channels at a rate of 1.2 L/min and was programmed to provide a size distribution every 6 s.

For the aerosol spectrometer measurements, participants were placed in an aerosol containment device, the SplashGuard Plexiglass box,²¹ developed at the University of Montreal to contain aerosols in clinical settings. The probe of the spectrometer was placed in front of the participant's mouth at a distance of approximately 10 cm. The experimental setup is shown in Figure 1A,B. A 5-min baseline measurement was first taken without a participant in the box to set background levels. Then, for every participant, the following protocol was conducted three times without a mask with a 2-min break between each step: (1) 2 min of normal breathing, (2) 5 min of normal speech, (3) 30 s of nasal speculum examination with mouth closed, (4) 1 min of mouth and pharynx examination with tongue depressor with subject alternating between /æ/ phonation humming and breathing by mouth, (5) 20 s of neck examination with mouth closed. (6) three simulated coughs, (7) three simulated sneezes, and (8) 90 s of flexible nasal laryngoscopy with repeated/e/phonation.

Following this part of the experiment and also for each participant, the following protocol was also conducted three times, first with a surgical mask and then with a two-layer cloth mask with a 2-min break between each step: (1) 2 min of normal breathing, (2) three simulated coughs, and (3) three simulated sneezes.

2.3 | Aerosol imaging

A high-speed pulsed laser (LDY303HE PIV, Litron Lasers Ltd., United Kingdom) with a plano-concave lens was used to create a divergent laser sheet at a 1000 Hz frequency. The laser was synchronized with a high-speed camera (Phantom V310, Vision Research, USA) set at a 200 Hz frequency and placed perpendicular to the sheet.

The participants were placed under the laser sheet with adequate protective eyewear for the following measurements: (1) flexible laryngoscopy with and without surgical mask, (2) sneeze (three times) followed by three rounds of simulated cough. The measurement setup is shown on Figure 1C. The measurements were repeated three times for every participant. Every laryngoscopy measurement lasted 13 s during which 2734 images were taken. For every sneezing and speaking followed by coughing measurement, 1300 images were taken in a 6-s time frame. Post-processing of the images was performed using

FIGURE 1 Experimental setup. The experimental setup for laser aerosol spectrometry viewed from the right (A) with the laser aerosol spectrometer (LAS) aspiration tube (red arrow) fixed 10 cm in front of the participant. The experimental setup for laser aerosol spectrometry viewed from the front left side with the circular doors (red arrow) opened for the practitioner to perform a flexible laryngoscopy without interfering with aerosol measurements (B). The experimental setup for live aerosol imaging showing the positioning of the camera, green laser sheet and participant (C).



Matlab “Image Processing Toolbox.” Images were cropped to a 625×800 pixel size to remove the participant's face and then binarized to identify particles using a fixed threshold on every image. For laryngoscopy images only, an additional filter removing objects bigger than 20 px^2 was implemented to reduce the errors of interpretation caused by the scope.

2.4 | Statistical analysis

Tests for statistical significance were one-way ANOVA, and p values less than .05 were considered significant with $*p < .05$, $**p < .01$,

$***p < .001$, and $****p < .0001$. Statistical analyses were performed using GraphPad Prism 9.0.0 statistical software (GraphPad Software Inc.).

3 | RESULTS

3.1 | Evaluation of aerosol generation using aerosol spectrometry

Aerosol generation was assessed in the SplashGuard Plexiglass box to prevent external airflow from perturbing aerosol measurements

(Figure 1A,B). The circular doors were opened for the practitioner to perform clinical exams without interfering with aerosol measurements. The aerosol generation for normal breathing, normal speech, tongue depressor examination with /æ/ phonation humming, neck examination with closed mouth, nasal speculum with closed mouth, and flexible laryngoscopy with /e/ phonation was evaluated using a LAS and normalized to \log_{10} particles per standard liter per minute (SLPM). (Figure 2). Normal breathing and normal speech were assessed both with a surgical mask and with no mask, while other procedures were assessed only with no mask as they are impossible to perform with the participant wearing a mask. Three different

participants were tested for every procedure, three times each (total $n = 9$). No particles were detected for all repetitions of normal breathing and speech with surgical mask (plotted at \log_{10} particles per SLPM = 0). No significant difference was observed between the six other conditions.

Since coughing and sneezing by patients are common during exams and often induced by clinical procedures such as flexible laryngoscopy, aerosol generation during such events was also quantified in comparison to normal breathing (Figure 3). Evaluations were performed using a LAS and normalized to \log_{10} particles per SLPM, during normal breathing with a surgical mask, normal speech with a surgical

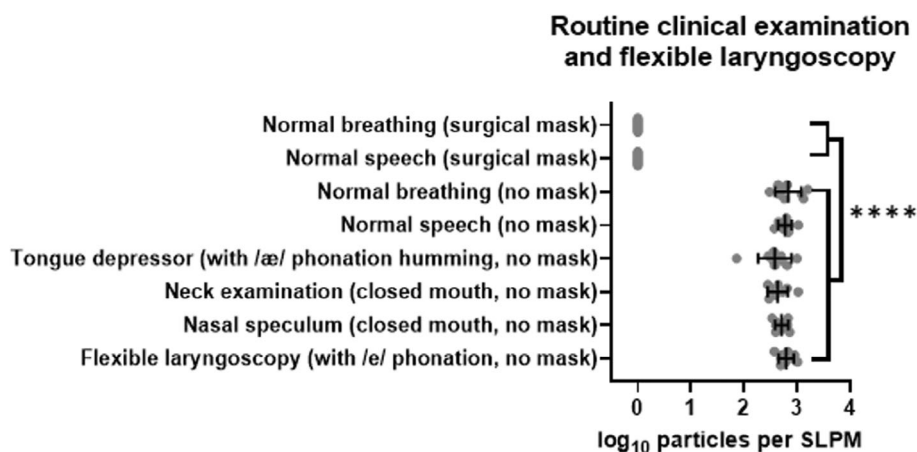


FIGURE 2 Aerosol and droplets quantification using aerosol spectrometry during normal breathing, normal speech, routine clinical examination procedures, and flexible laryngoscopy. Normal breathing and normal speech were assessed both with a surgical mask and with no mask, while other procedures were assessed only with no mask as they are impossible to perform with the participant wearing a mask. Procedures were performed in the SplashGuard Plexiglass box. Particles were counted using a LAS and normalized to \log_{10} particles per SLPM. Three different participants were tested for every procedure, three times each (total $n = 9$). No particles were detected for all repetitions of normal breathing and speech with surgical mask (plotted at \log_{10} particles per SLPM = 0). No statistical difference was observed between the six tests with no mask.

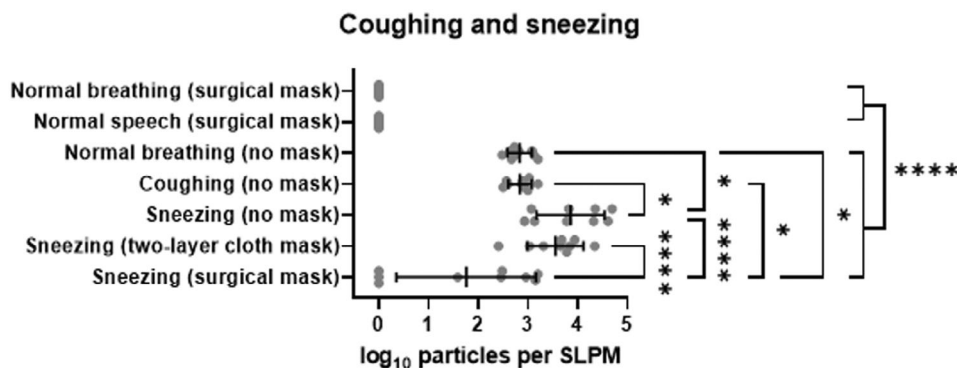


FIGURE 3 Aerosol and droplets quantification using aerosol spectrometry for coughing and sneezing. Evaluations were performed during normal breathing with a surgical mask, normal speech with a surgical mask, normal breathing without mask, coughing without mask, and sneezing simulations without mask or with two-layer cloth mask and surgical masks. Procedures were performed in the SplashGuard Plexiglass box. Particles were counted using a laser aerosol spectrometer (LAS) and normalized to \log_{10} particles per standard litre per minute (SLPM). Three different participants were tested for every procedure, three times each (total $n = 9$). No particles were detected for all repetitions of normal breathing and speech with surgical mask and for three repetitions of sneezing with surgical mask (plotted at \log_{10} particles per SLPM = 0). Statistical comparison to normal breathing is shown for every test.

mask, normal breathing without mask, coughing without mask, and sneezing simulations without mask or with two-layer cloth mask and surgical masks. No statistical difference was observed between normal breathing and coughing, but it is important to point out that the aerosol spectrometry we used does not measure the distance traveled by particles. No particles were detected for all repetitions of normal breathing and speech with surgical mask and for three repetitions of sneezing with surgical mask (plotted at \log_{10} particles per SLP = 0). On the other hand, sneezing showed a significant increase in particles emitted. The use of a two-layer cloth mask lowered the number of particles detected after sneezing but was not significant, whereas a surgical mask decreased particle counts to lower than normal breathing. Normal breathing and coughing with a surgical mask prevented detectable particle counts.

3.2 | Evaluation of aerosol generation using laser aerosol imaging

For flexible laryngoscopy, we aimed to measure more precisely any particles ejected at the moment when the scope was retrieved from the nostril. As this moment is very brief, we used a measuring technique that provided high temporal resolution. We used high-speed laser aerosol imaging to visualize aerosol particles and their trajectories. When the flexible laryngoscopy procedure was performed with the participants not wearing a mask (Videos S1 and S2), a small outburst of particles was visible at the end of the laryngoscopy for one of the participant (Figure 4A and Video S1) due to the participant releasing his breath at the end of the procedure. With the participants wearing a mask over the mouth, we observed no outburst of aerosols

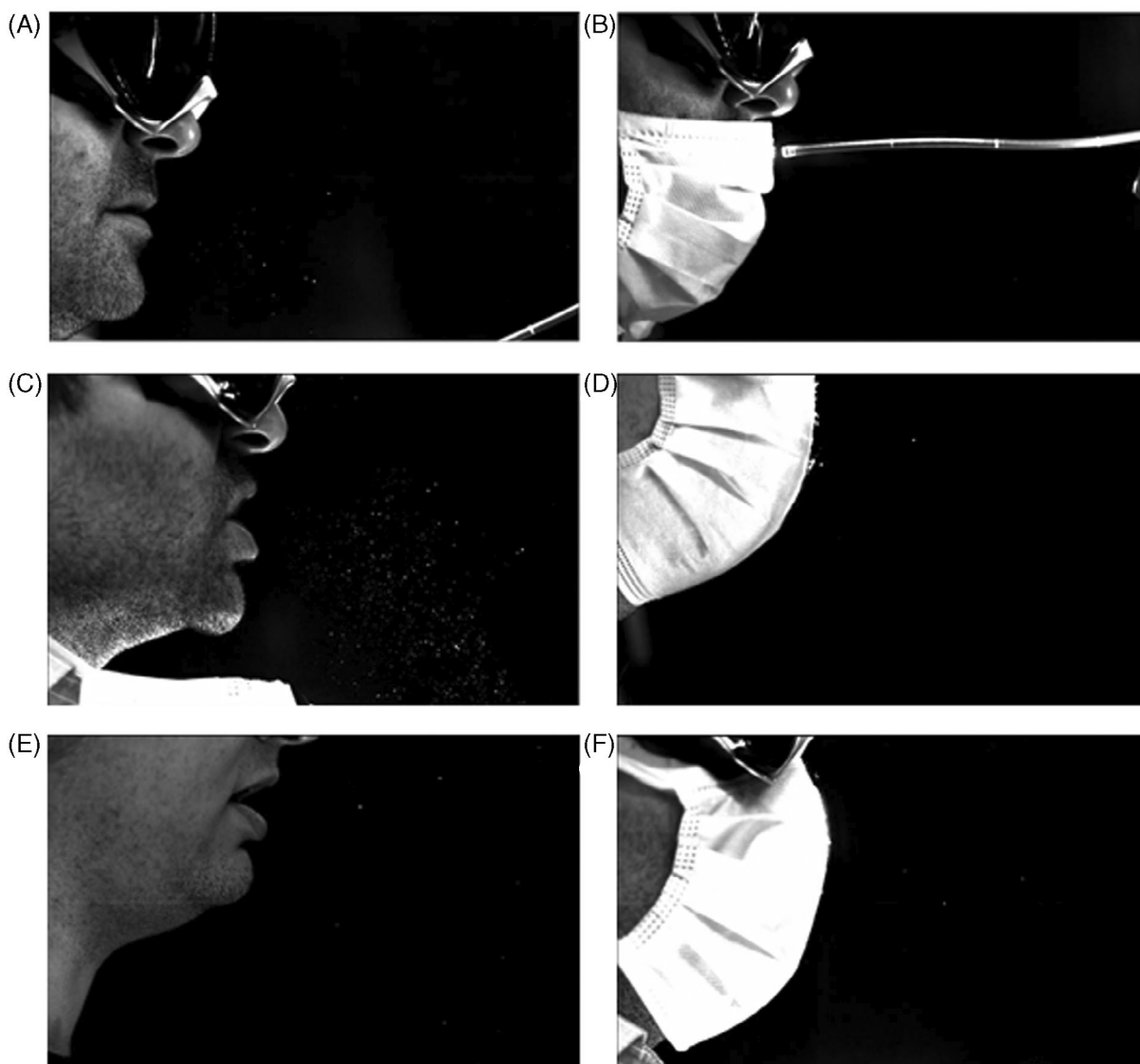


FIGURE 4 Laser aerosol imaging representative images. Aerosol and droplets visualization during flexible laryngoscopy removal with the participant with no mask (A) and wearing a surgical mask (B) during the procedure. Aerosol and droplets visualization during sneezing with the participant with no mask (C) and wearing a surgical mask (D). Aerosol and droplets visualization during coughing with the participant with no mask (E) and wearing a surgical mask (F). Complete videos are available in online-only material.

during and after the removal of the flexible laryngoscope (Figure 4B and Videos S3 and S4). Importantly, no visible outburst of particles are seen when the scope was retrieved from the nostril.

As sneezing and coughing can occur during ENT examination or flexible laryngoscopy, we also visualized aerosols during sneezing (Figure 4C,D and Videos S5–S8) and coughing (Figure 4E, F and Videos S9–S12), with and without surgical masks. Again, more aerosols were observed during sneezing than coughing. For both procedures, the surgical mask greatly reduced aerosol generation.

4 | DISCUSSION

In the early stages of the COVID-19 pandemic, physical examinations of patients came to a halt in favor of telemedicine. Fear of aerosol transmission to health professionals led to complex protocols for ENT examination and flexible laryngoscopy. However, guidelines were inferred without a proper understanding of aerosol and particle generation during these procedures. While the patient is in the examination room, possible sources of transmission include normal breathing, speech, upper airway examination, flexible laryngoscopy, and finally coughing or sneezing. These clinical scenarios were all included in our evaluation of aerosol and droplets production around the participants. The use of the Splashguard Plexiglass box provided a controlled environment to allow for precise aerosol sampling and eliminated external factors. This containment approach likely overestimated the amount of aerosols encountered when performing the same activities in a larger examination room.

Results from this study show that ENT exam and flexible laryngoscopy are not aerosol-generating procedures. The only event that resulted in a significant increase in aerosol production, as measured by spectrometry, was sneezing. This was significantly reduced by the appropriate use of a procedure mask, covering both the mouth and nose. During flexible laryngoscopy, there was no significant aerosol or droplet generation measured in the present study. This is a reassuring finding as flexible laryngoscopies were significantly affected at the beginning of the pandemic, delaying diagnosis and treatment. However, the clinician must bear in mind that coughing or sneezing can occur during flexible laryngoscopy and could in itself be aerosol-generating. Covering the mouth with a procedure mask can further reduce that risk.

Unlike other approaches using liquid tracers such as fluorescein in manikins or cadavers where particle size distribution is estimated from droplet deposition on surfaces, the methods used in this study provide direct information on airborne particles produced directly by patients during a realistic routine clinical examination and flexible laryngoscopy. Furthermore, the use of a high-speed laser and camera setup offers visual insights on key aerosol-generating events that could occur during regular examination and allows visualization of particle trajectories.

The main limitation of this study is that it included healthy participants without COVID-19 symptoms. Also, coughs and sneezes were simulated and it is possible that more aerosols would be measured on symptomatic participants.

5 | CONCLUSION

Routine ENT examination during which the patient cannot wear a mask have a comparable aerosol production to normal breathing. Therefore, similar safety measures should be applied. The practitioner should wear a surgical mask and potentially contaminated surfaces should be cleaned after the procedure. For flexible laryngoscopy, aerosol production is also comparable to normal breathing, and it is recommended that the patient wear a mask over the mouth in addition to the practitioner wearing a surgical mask. Cleaning of potentially contaminated surfaces should also be conducted after the procedure, and the time during which the patient is unmasked should be minimized. In these settings, the risk to the practitioner is minimal unless the patient is sneezing, which contributes to a significant increase in aerosol production in comparison to normal breathing. In order to minimize this risk, wearing a mask appropriately over the mouth and nose significantly reduces aerosol production during sneezing, particularly with a surgical mask, which is more effective than the two-layer cloth mask.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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