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Aerosol and droplet generation in upper and lower GI endoscopy: whole procedure and event-based analysis

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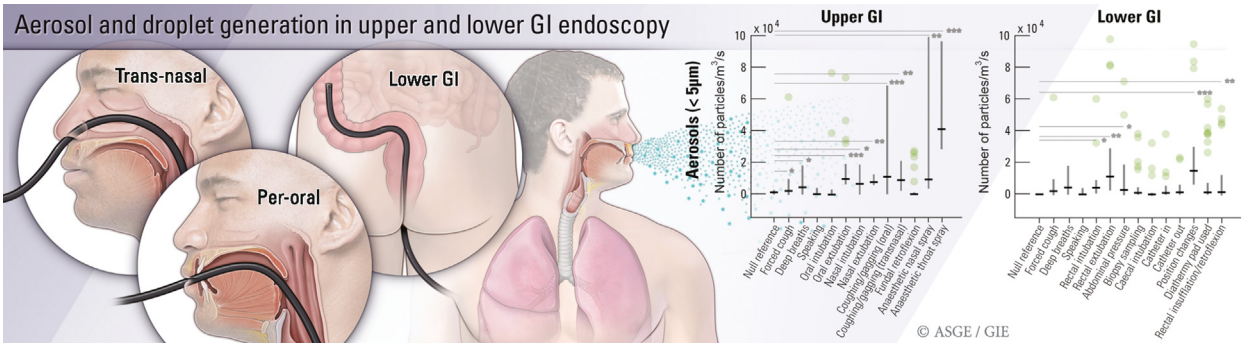
GRAPHICAL ABSTRACT



Background and Aims: Aerosol-generating procedures have become an important healthcare issue during the coronavirus disease 2019 (COVID-19) pandemic because the severe acute respiratory syndrome coronavirus 2 virus can be transmitted through aerosols. We aimed to characterize aerosol and droplet generation in GI endoscopy, where there is little evidence.

Methods: This prospective observational study included 36 patients undergoing routine peroral gastroscopy (POG), 11 undergoing transnasal endoscopy (TNE), and 48 undergoing lower GI (LGI) endoscopy. Particle counters took measurements near the appropriate orifice (2 models were used with diameter ranges of .3-25 µm and 20-3000 µm). Quantitative analysis was performed by recording specific events and subtracting background particles.

Results: POG produced 1.96 times the level of background particles ($P < .001$) and TNE produced 2.00 times ($P < .001$), but a direct comparison showed POG produced 2.00 times more particles than TNE. LGI procedures produced significant particle counts ($P < .001$) with 2.4 times greater production per procedure than POG but only .63 times production per minute. Events that were significant relative to the room background particle count were POG, with throat spray (150.0 times, $P < .001$), esophageal extubation (37.5 times, $P < .001$), and coughing or gagging (25.8 times, $P < .01$); TNE, with nasal spray (40.1 times, $P < .001$), nasal extubation (32.0 times, $P < .01$), and coughing or gagging (20.0, $P < .01$); and LGI procedures, with rectal intubation (9.9 times, $P < .05$), rectal extubation (27.2 times, $P < .01$), application of abdominal pressure (9.6 times, $P < .05$), and rectal insufflation or retroflexion (7.7 times, $P < .01$). These all produced particle counts larger than or comparable with volitional cough.

Conclusions: GI endoscopy performed through the mouth, nose, or rectum generates significant quantities of aerosols and droplets. Because the infectivity of procedures is not established, we therefore suggest adequate personal protective equipment is used for all GI endoscopy where there is a high population prevalence of COVID-19. Avoiding throat and nasal spray would significantly reduce particles generated from upper GI procedures. (Gastrointest Endosc 2022;96:603-11.)

(footnotes appear on last page of article)

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus responsible for coronavirus disease 2019 (COVID-19), can be transmitted through aerosols.[1-3] Aerosol-generating procedures (AGPs) therefore represent a transmission risk to healthcare workers and have become an important healthcare issue.[4] Aerosols are in the respirable range, meaning they can deposit in the lower airways to cause infection via airborne transmission.[4] In contrast, droplets are larger and gravitationally settle rapidly or can be inhaled at close contact, although resuspension into the air can occur from droplets on clothing or surfaces.[1] The World Health Organization has defined aerosols as particles <5 μm and droplets as ~5 to 10 μm.[5,6]

The definition of an AGP lacks consensus: the World Health Organization defines this as any medical procedure that can induce the production of aerosols of various sizes, including particles <5 μm.[5] However, Public Health England only considers AGPs as those resulting in the release of airborne particles from the respiratory tract.[7] Further difficulty with definitions occurs because heavy breathing, talking, coughing, and singing all generate particles of varying sizes, including aerosols.[8,9]

The World Health Organization has produced a list of AGPs mainly based on evidence from small, retrospective, epidemiologic studies linking these procedures with greater risk for healthcare worker infections.[10] Aerosol or droplet levels were not measured in these studies, so the exact mode of transmission was not known. Although GI endoscopy is not on this list, various professional societies have designated upper GI (UGI) endoscopy as an AGP and lower GI (LGI) endoscopy at least of uncertain risk status, based on theoretical grounds.[11-14] This has had important repercussions, including postponed procedures, lost capacity, and use of enhanced personal protective equipment.

Two recent studies have provided evidence of aerosol generation during UGI endoscopy using handheld particle counters. Chan et al[15] showed that aerosols are generated during UGI endoscopy and that continuous suction reduced aerosols, whereas the level of sedation had little effect. Sagami et al[16] showed that aerosols increased significantly in a plastic enclosure around patients' heads during UGI endoscopy compared with a control group. We emphasize that particle-counting approaches alone do not directly test whether there is viable virus material in droplets and aerosols; for this, an air-sampling approach is required.[1] However, aerosol and droplet transmission is widely agreed to be the most important physical transmission route for SARS-CoV-2 and so serves as an important proxy indicator for potential infectivity.[2]

Our study aims to characterize aerosol and droplet generation in GI endoscopy performed through the mouth, nose, or rectum by quantifying particles across entire procedures and specific events during procedures and analyzing associated risk variables. This information is important in ensuring the safety of GI endoscopy for patients and healthcare workers for both current and future respiratory and GI pathogens.

METHODS

Study design and participants

For this prospective, observational study, Health Research Authority and ethical approval was granted by the Wales Research Ethics Committee before the start of the study. Consent was obtained from all patients.

We included patients undergoing routine UGI and LGI endoscopy on the lists of 13 different participating endoscopists at the Endoscopy Unit of the Nottingham University Hospitals NHS Trust Treatment Centre between October 2020 and March 2021. Inclusion criteria were adult patients aged >18 years with capacity to consent. For reasons of practicality, entire lists were selected for recruitment, and all those on each list who met the inclusion criteria were invited to participate. Procedures were performed as they normally would be in clinical practice. Patients chose whether they wanted sedation, and endoscopists chose whether to use CO_2 only or water immersion for insertion during LGI procedures. All UGI procedures were performed with CO_2 or air for insufflation, and intermittent suctioning was used for all peroral gastroscopies (POGs).

Using data from previous studies that measured particle counts and sizes for coughs and sneezes, we calculated a measurable effect size (Cohen's d) of 1.98 or less to differentiate between relevant events (eg, cough vs sneeze). This was computed by comparing the differences in mean particle counts divided by the standard deviation for datasets of coughs and sneezes.[17,18] We then computed that measuring this effect size would require at least 5 repeats of each procedure type tested.

To standardize procedures, we used endoscopy rooms within the same endoscopy suite, which all had room ventilation set at 15 to 17 air changes per hour and a similar size, air temperature, and humidity level. We minimized unnecessary airflow, for example, by not allowing the room doors to be opened during the procedures and only allowing 1 additional person (the research nurse) in the room. All present in the room wore enhanced personal protective equipment that minimized additional human aerosol sources.

Patient and public involvement

The Nottingham University Hospitals' NHS Trust hosts an NIHR Gastrointestinal & Liver Biomedical Research Centre, through which a patient advisory group was formed. Three members of this group were recruited to approve the significance of the study and acceptability of the methodology. They also ensured the patient information sheet and consent form were easily understandable.

Measurement methodology

We used 2 pieces of equipment to measure particle sizes. The first was a AeroTrak portable particle counter (TSI, Shoreview, Minn, USA, model 9500-01), which previous studies have used for respirable particle sizing in medical contexts.[19,20] This measured particles in 6 diameter ranges (.5-.7 μm, .7-1.0 μm, 1.0-3.0 μm, 3.0-5.0 μm, 5.0-10.0 μm, and 10.0-25 μm) at a flow rate of 100 L/min. A 2-m tube (manufacturer provided) was connected to an isokinetic inlet head placed 10 cm from the patient's mouth for UGI procedures and approximately 20 cm from the patient's anus for LGI procedures using an articulating arm. These distances were chosen for compatibility with previously published studies[13] and represent an acceptable tradeoff between practicality (such as access of scope and need to change patient position) and maximizing aerosol capture (known to be reduced significantly by 2 m in a room with high background particles[21]). The operator's hands are kept >50 cm from the air inlet head to avoid interference from leakage through the endoscope's suction and air and water control buttons. The effect of tube length on larger particles is accounted for by a calibration experiment in a room at equilibrium using a .02-m tube.

The second instrument used was an VisiSize spray characterization tool (Oxford Lasers, Didcot, UK, model N60) that was used in 4 POGs. Spray characterizers have previously been used for characterizing coughs and sneezes.[17] The configuration we used allowed sizing of particles from ~10 μm to 3.5 mm in diameter. It is important to consider these 2 size ranges because respiratory aerosols are believed to be polydisperse, with 2 size peaks at around 1 μm and 100 μm in diameter.[21] The instrument images particles that pass through a small volume located between a laser head and a camera (dimensions of 12.6 × 7.2 × 50 mm = 4536 mm^3). The instrument is placed such that this volume is located 10 cm from the mouth of the patient (see Supplementary Fig. 1, available online at www.giejournal.org).

During the procedure, an observation camera with a timestamp feature was used to record audio and video for synchronization purposes. For each procedure, an experienced research nurse recorded information on a case report form containing demographics (age, sex, body mass index [BMI]) and variables determined during the procedure (sedation type, degree of discomfort, use of CO_2 or water for LGI procedures, subjective 3-tier estimate of anal tone taken during the preprocedure digital rectal examination and representing pressure required for insertion, and presence of hiatus hernia). During the procedure, the times of relevant events, beginning when the patient entered and ending after the patient left, were recorded along with the time in seconds (Supplementary Methods, available online at www.giejournal.org). Periods of time when there were no significant events (eg, lengthy examinations without patient movement) were identified and marked as "null reference" events.

Our measurements did not detect statistically significant particle production from rectal insufflation events or injection of water through the scope, which indicates leakage is not likely a significant source of interference. However, our use of intermittent suctioning as per standard protocol may reduce measured particle counts by up to 50%,[15] although we noted that those particles not captured by suctioning posed the main airborne viral transmission risk, so our measurements have high relevance for infection control.

Data processing

Analysis of full procedure data. We first considered the total particle count across each procedure for 2 particle diameter ranges, .5 to 5 μm (aerosols) and 5 to 25 μm (droplets), with patient position changes suppressed. The time period considered started from either anesthetic spray (UGI) or intubation (LGI) and ended at extubation. This was compared with a reference window before the procedure began and was normalized to account for different durations. The fallow period of 20 minutes between procedures should minimize interference from residual particles, but for comparison we also considered an alternative method that used a background removal technique based on smoothing to estimate particle counts (see Supplementary Methods, available online at www.giejournal.org).

Causal event-based model. We next applied our causal event–based model, which essentially takes a difference in particle counts before and after an annotated event (eg, cough) to estimate the number of particles produced by the event. For each annotated event, we first estimated the room background particle count immediately before the event by smoothing the data over a 105-second window. We then subtracted this background from the raw particle count immediately after the event, averaged over a window of 15 to 30 seconds. To validate this approach, we also applied it to several periods when there was no annotated event, and therefore the difference was expected to be approximately zero.

Statistical analysis

Building on existing models of aerosol production in the respiratory tract,[20] we used a log-normal distribution to model the distribution of total particle counts across different instances of each event. For the entire procedure data, a t test was applied to compute P values. For the causal event model the data distribution can be modeled as the sum of a log-normal and normal distribution to account for negative values of particle counts that can arise from the subtraction step. A Monte-Carlo sampling (or bootstrapping) method was therefore used to provide numerical estimates of P values.[22]

RESULTS

Demographics

Overall, we recorded 48 UGI procedures (37 peroral, 11 transnasal) and 48 LGI procedures (37 colonoscopies, 11 flexible sigmoidoscopies). Because of the recruitment of entire lists, 46% of procedures were consecutive; however, we did not find any statistically significant correlation between consecutive procedures in terms of particle counts. Of the UGI procedures, 17 patients were asked to perform a volitional cough and 12 to perform deep breathing and speaking for reference.

Of the 96 patients, 52 were men and 44 were women, with a median age of 62 years (range 23-93) and median BMI of 25.5 kg/m^2 (range, 16.3-56). Fourteen patients reported themselves as a smoker, whereas 82 did not. For sedation in UGI procedures, 15 patients had midazolam ± fentanyl and 33 were unsedated. All procedures used xylocaine throat or nasal spray. In LGI procedures, 19 patients had midazolam ± fentanyl, 24 had Entonox (BOC Healthcare, Manchester, UK), and 4 had no sedation. Anal tone was low in 5 patients, medium in 21, high in 14, and not recorded in 8. LGI procedures used CO_2 in 42 procedures and water in 6. Discomfort was characterized as low in 56 patients, medium in 33, high in 3, and not recorded in 4. A hiatus hernia was reported in 12 patients but not in 36. Diverticular disease was mild in 4 patients, extensive in 4 patients, and not found in 40.

Entire procedure analysis

Over the full range of particle sizes (.5-25 μm) and normalized to procedure duration, POG produced significantly higher particle counts than the reference background (1.96 times; 95% CI, 1.61-2.38; $P < .001$; n = 37) as did TNE (2.00 times; 95% CI, 1.53-2.62; $P < .001$; n = 11). However, when directly comparing POG and TNE, we found that POG produced significantly more particles (1.99 times; 95% CI, 1.28-3.12; $P < .01$). LGI procedures (with patient position changes excluded) were significantly higher than the reference background (1.34 times; 95% CI, 1.14-1.59; $P < .001$; n = 48) but less so than UGI procedures. When applying background removal, we found that the ratios compared with the reference window increased approximately by a factor of 3 with the main trend preserved. However, we found that the ratio between POG and TNE became nonsignificant ($P = .411$), which indicates the importance of slow but continuous production of aerosols during POG, as opposed to event-driven "spikes" that were removed by our background subtraction technique. When excluding the anesthetic spray from our analysis, we found the ratios compared with the reference window were reduced by about 36% for both POG and TNE but were still significant ($P < .01$ and $P < .05$ respectively), indicating the importance of anesthetic spray as a driver of particle production, which agreed with our event-based analysis.

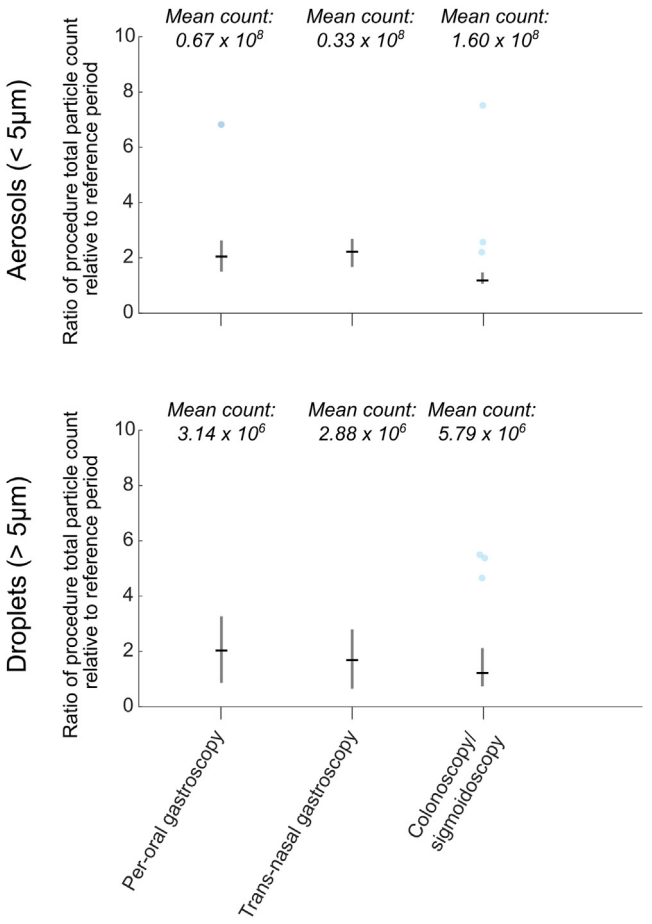


Figure 1. Ratios of particle counts over entire procedures relative to a reference period before the start of the procedure (normalized to procedure duration). *White circles* indicate median values, with raw mean counts (not normalized to procedure duration) shown above.

The absolute number of particles was on average less for POG than for LGI procedures (.71 × 10^8 vs 1.69 × 10^8) but was greater when procedure duration (intubation to extubation) was taken into account: POG produced particles at a rate of 13.9 × 10^6 per minute/m^3 (95% CI, 7.3 × 10^6 to 20.5 × 10^6) versus 8.8 × 10^6 per minute/m^3 (95% CI, 4.0 × 10^6 to 13.6 × 10^6) for LGI procedures, excluding position changes. The median duration of recorded procedures was 7.2 minutes for UGI procedures and 24.7 minutes for LGI procedures. Within the LGI procedures we did not find significant differences between colonoscopy and sigmoidoscopy in terms of particle production rate ($P = .168$), although the absolute number of particles was larger for colonoscopy (1.86 × 10^8 vs 1.23 × 10^8) because the procedures were longer (median, 26.0 minutes vs 10.3 minutes).

For particles >5 μm in diameter we found that LGI procedures were no longer significant relative to the background ($P = .082$). For particles <5 μm in diameter we found all procedure types were significantly higher than the reference background (POG, 1.99 times; TNE,

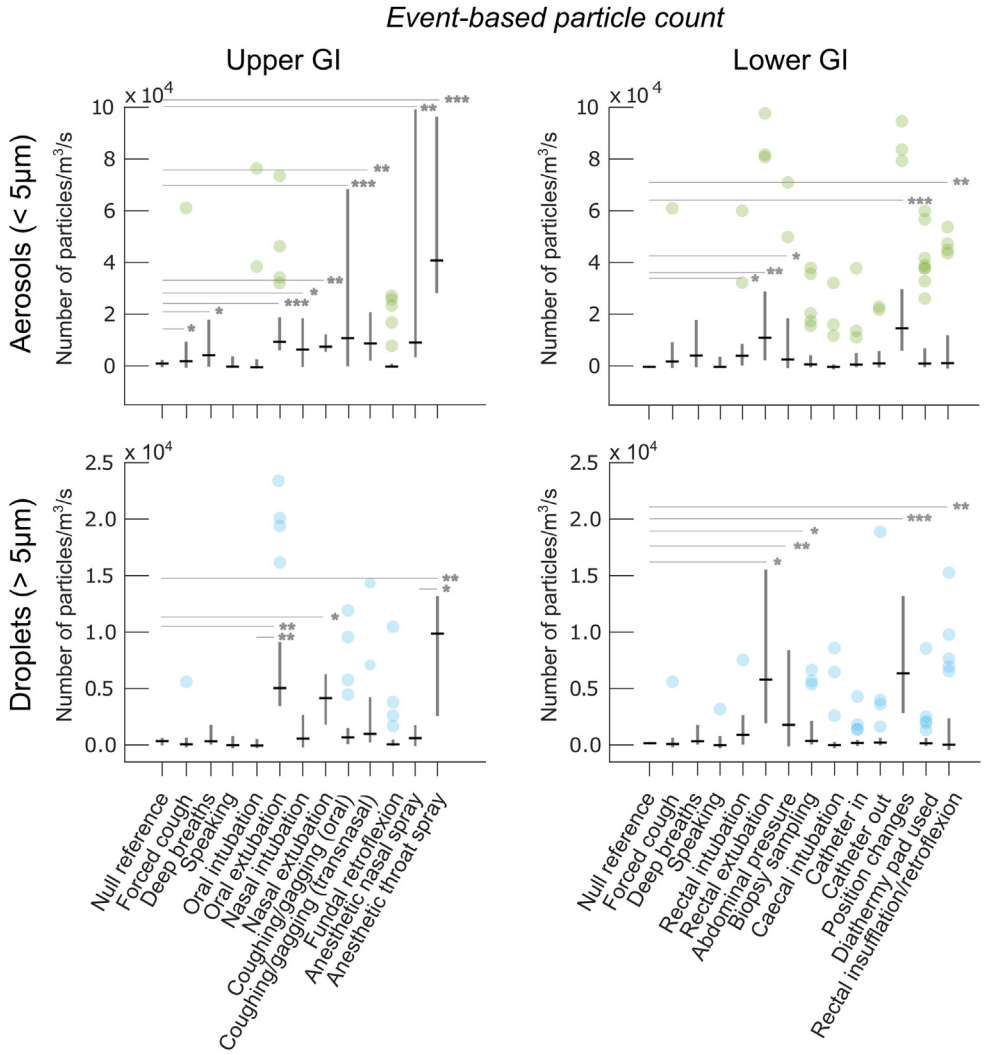


Figure 2. Particle production by individual events measured during upper and lower GI procedures. Numbers of recorded events are shown. *Black dashes* represent medians. *$P < .05$, **$P < .01$, ***$P < .001$. For readability, only a selection of salient statistical relationships are shown.

2.09 times; LGI endoscopy, 1.34 times; $P < .001$). The particle counts, normalized to procedure duration, relative to the reference background are summarized in Figure 1.

Regarding variables, the only significant result for LGI procedures was that patient discomfort rated as high resulted in more particles than discomfort rated as low (6.3 times; 95% CI, 1.6-25.3; $P < .01$). For UGI procedures there was a small statistically significant ($P < .05$) negative correlation between particle count and age ($r^2 = .09$). Other variables, including BMI, use of sedation, use of CO_2 or water for insertion, were not found to have a significant effect.

Causal event–based analysis

Figure 2 shows individual events. For UGI procedures we found the following events significant relative to the room background particle count: nasal intubation (10.9 times; 95% CI, .68-256.6; $P < .05$; n = 11), oral extubation (37.5 times; 95% CI, 6.3-619.3; $P < .001$; n = 35), nasal extubation (32.0 times; 95% CI, 4.0-612.4; $P < .01$; n = 11), coughing or gagging during oral endoscopy (25.8 times; 95% CI, 3.5-483.5; $P < .01$; n = 28), coughing or gagging during TNE (20.0 times; 95% CI, 2.3-398.0; $P < .01$; n = 17), forced coughing (7.5 times; 95% CI, .67-143.7; $P < .05$; n = 17), deep breathing (15.7 times; 95% CI, 1.4-329.8; $P < .05$; n = 12), anesthetic nasal spray (40.1 times; 95% CI, 4.6-737.1; $P < .001$; n = 13), and anesthetic throat spray (150.0 times; 95% CI, 19.4-2697.0; $P < .001$; n = 30). Oral intubation ($P = .443$, n = 32) and speaking at low volume ($P = .170$, n = 12) were not significant, which is consistent with previous studies.[6]

For LGI procedures we found several events that were significant relative to the room background particle count: rectal intubation (9.9 times; 95% CI, 1.5-112.1; $P < .05$; n = 45), rectal extubation (27.2 times; 95% CI, 6.0-317.7; $P < .01$; n = 49), application of abdominal pressure

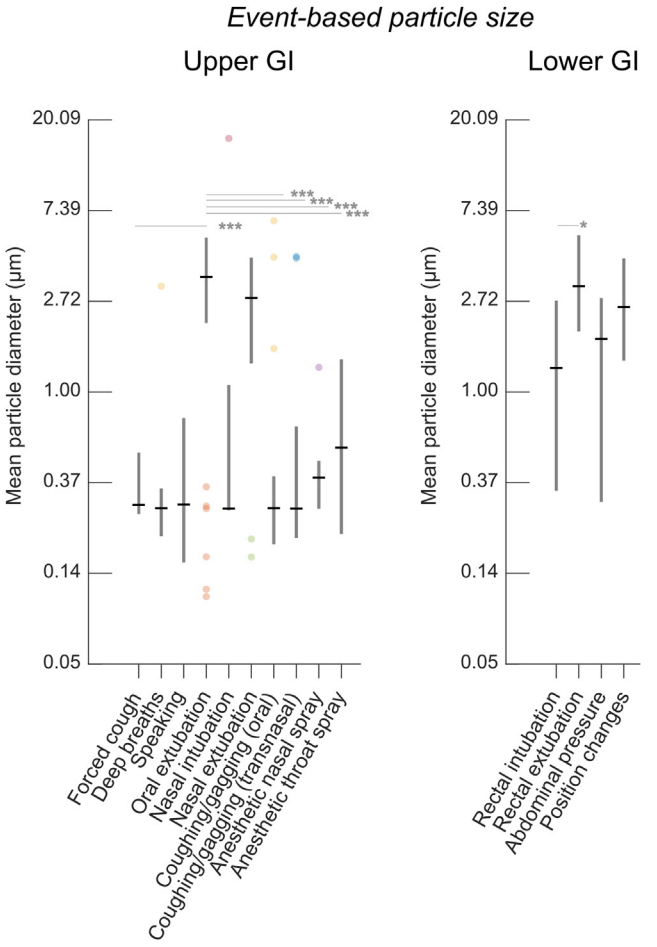


Figure 3. Particle size distribution for statistically significant particle generating events. *P < .05, **P < .01, ***P < .001. Note that for readability, only a small selection of salient statistical relationships are shown.

(9.6 times; 95% CI, 1.3-130.1; P < .05; n = 22), patient position changes (34.9 times; 95% CI, 9.5-382.8; P < .001; n = 98), and rectal insufflation or retroflexion (7.7 times; 95% CI, 1.5-98.8; P < .01; n = 39). We observed that rectal extubation produced significantly more particles than intubation (3.3 times; 95% CI, 1.1-8.6; P < .05). Biopsy sampling, insertion and removal of catheters, water injection, and use of diathermy cutting were not significant.

Comparison with volitional coughing

To examine the relevance for potential airborne pathogen spread, we next compared the events to volitional coughing, in line with previous work.[6] For UGI procedures, we found the following events to be statistically indistinguishable from the mean volitional cough: coughing or gagging during TNE (P = .116), deep breaths (P = .187), and speaking (P = .230). However, some events produced significantly more particles: oral extubation (4.0 times; 95% CI, 1.6-27.1; P < .01), anesthetic throat spray (10.5 times; 95% CI, 1.2-80.1; P < .05), nasal extubation (4.2 times; 95% CI, .9-20.5; P < .05), coughing or gagging during POG (3.5 times; 95% CI, .8-20.5; P < .05), an anesthetic nasal spray (5.5 times; 95% CI, .9-43.9; P < .05).

For LGI procedures, particle generation was comparable with a forced cough for intubation (P = .404), extubation (P = .171), and abdominal pressure (P = .212). However, significantly more particles were produced for rectal extubation (5.9 times; 95% CI, 1.5-40.4; P < .01) and position changes (7.0 times; 95% CI, 2.0-40.9; P < .05).

Particle size analysis

The size range of particles associated with each event is shown in Figure 3. For UGI procedures, oral extubation produced particle sizes significantly larger than volitional coughing (2.2 µm vs .32 µm, P < .001 for both), whereas particle sizes were similar for involuntary coughing or gagging (oral, .44 µm, P = .36; nasal, .68 µm, P = .35). Both anesthetic throat spray (P = .09) and nasal spray (P = .31) produced particles statistically similar in size to coughing. For LGI procedures, rectal extubation produced particles of a similar mean size as oral extubation (2.0 µm, P = .226). Patient position changes produced particles comparable with rectal extubation (1.7 µm, P = .30).

To examine the effect of larger particles (>10 µm), we used a spray characterizer to record 4 separate POGs. We observed a strong temporal correlation in particle counts between this instrument and the AeroTrak, which confirms that both instruments were recording the same particle-producing events (Supplementary Fig. 2, available online at www.giejournal.org). The cases examined had insufficient data for a full statistical analysis, but we found that oral extubation and fundal retroflexion produced particles up to 300 µm (mean measured diameter, 32 µm), whereas coughing or gagging did not produce detectable particles in this range (Supplementary Fig. 1).

Impact of variables

Finally, we analyzed the effect of measured variables on event-based particle production. In the presence of a hiatus hernia, there was a much larger increase in particle generation during volitional coughing (23.2 times; 95% CI, 1.6-346.7; P < .05), which may warrant further investigation. We also noted that on average there were 2.5 times as many coughing or gagging events per procedure for patients with hiatus hernia (P < .05). For UGI procedures, the impact variables on particle size was limited. For LGI procedures, the variables had a minimal effect on rectal intubation and rectal extubation: Sedation, anal tone, and age were not statistically significant.

DISCUSSION

This is the first study to report that both TNE and LGI endoscopy are aerosol and droplet generating. We are also the first to report on defined particle-generating

events and associated particle sizes within procedures performed through the mouth, nose, and rectum. Both POG and TNE should therefore be classed as AGPs, whereas the classification of LGI endoscopy depends on the definition of AGP used. For UGI endoscopy, in some countries the use of patient facemasks is becoming widespread, although few studies have quantified their impact on aerosol and droplet generation.[23] A randomized study recently found that a mouthpiece did not produce smaller size particles (<1.0 μm), which in the context of our findings may suggest limited reduction of risk.[24] Further studies in this area are certainly warranted. However, our aim here was to establish the expectation during standard endoscopy, without the use of facemasks, which is still the usual practice in most endoscopy units worldwide.

With regard to POG, our results confirm those of previous studies showing this is an AGP, producing particles at double the background level. The most significant contributing event is local anesthetic throat spray application, which generates 10 times the number of particles compared with a volitional cough, with an average particle size in the aerosol range. By comparison, a recent study showed that controlled endotracheal intubation and extubation in asymptomatic patients generated only a fraction of the aerosols generated by volitional coughing.[25] The particles recorded with throat spray application are potentially infectious, because they would have rebounded from the patient's oropharynx or occasionally from coughing induced by the throat spray. There is additional risk because the throat spray is applied face-on with the patient. It is therefore important that barrier methods such as face shields or goggles are used while applying throat and nasal spray.

Extubation is the second-most particle-generating event in POG and is also significantly more particle-generating than volitional cough. However, a higher proportion of particles is in the droplet range (and reaches up to 3000 μm), which has a lower risk for airborne transmission. This is understandable because both insufflation in the esophagus and movement of the wet shaft of the endoscope on extubation generate particles.[8] Coughing or gagging is also a significant generator of particles and is predictably comparable with the level of particles produced by volitional coughing, although we did not find that the use of sedation reduced particle counts over the whole procedure. The usefulness of suctioning, described by Chan et al,[15] was not discussed in our study, because intermittent suctioning was applied in all our cases.

Interestingly, during volitional coughing, we found the presence of a hiatus hernia produced increased levels of particles, with an average size in the aerosol range. This may be because of the loss of the physiologic lower esophageal sphincter, which would enable aerosols to be expelled unimpeded from the stomach and out of the mouth as abdominal muscles are contracted during coughing. Previous studies have found a negligible impact of sedation on aerosol production, in agreement with our findings, but have found significant positive correlation with BMI, which we did not observe.[15,16] We expect this is because of increased interpatient variation in our study caused by looser confinement of aerosols; for example, a previous study placed the patient's head in an enclosure.[16] However, we purposefully designed our study with looser constraints to enable direct comparison between UGI and LGI procedures (for which building a suitable enclosure would be challenging) and to replicate realistic procedure conditions to measure aerosol exposure likely to be experience by healthcare workers.

TNE has been suggested by some as a non-AGP method for performing UGI endoscopy, although the generation of aerosols from intranasal application of spray has already been suggested.[26,27] Our results show that TNE is an AGP and produces particles predominantly in the aerosol range, which may also have implications for similar otolaryngology procedures. Nasal spray application, nasal intubation, and nasal extubation were all associated with significant spikes of particles. TNE generates approximately half the level of particles of POG; therefore, if used with additional mitigating strategies (avoidance of nasal spray, barrier methods), TNE could potentially become a non-AGP procedure.

With regard to LGI endoscopy, our study shows the absolute levels of particles produced are greater than UGI procedures but are about one-third lower when taken per unit of time. Although there would be a greater exposure to aerosols in LGI procedures because of longer procedures, these are therefore more likely to be cleared in well-ventilated rooms. We recognize that COVID-19 is primarily a respiratory pathogen, and fecal–oral transmission has not been proven. The risk from LGI procedures is likely to be considerably lower than equivalent aerosols generated by UGI procedures. However, it should be noted that infection of intestinal cells and viral replication has been shown,[27] and SARS-CoV-2 RNA has been detected in stool,[28] whereas there are also implications for other types of GI pathogens. There have been attempts to mitigate aerosol and droplet diffusion during colonoscopy using specially designed shorts with a diaphragm to pass the colonoscope.[29]

An important source of interference to consider for LGI endoscopy occurs during patient position changes. We observed that turning a patient before the procedure has even begun resulted in a large spike in measured particles, which is probably because of air movement and rubbing of materials. The clinical relevance of position changes is therefore difficult to interpret, but we are able to identify, isolate, and exclude these from analysis where appropriate.

In this study, we characterized aerosol and droplet generation from the different routes of GI endoscopy. We emphasize, however, that aerosols may not necessarily contain viable virus material, and so their generation

does not equate to infectivity of the procedures themselves. This depends on multiple factors, including from which part of the patient the particles are generated. Particles from the oral and nasal cavities are likely to have a much higher potential infectivity risk compared with those from the large bowel. Because the infectivity of procedures is not established, we therefore suggest adequate personal protective equipment (including high-efficiency masks) and sanitization of floors and surfaces (to prevent resuspension of aerosols) are used for all GI endoscopy where there is a high population prevalence of COVID-19.

In conclusion, our study shows endoscopic procedures performed through the mouth, nose, or rectum generate aerosols and droplets and that individual events produce greater or comparable levels of particles compared with volitional cough. For UGI endoscopy, our results suggest aerosol generation can be greatly reduced by avoiding or finding alternatives to throat spray and by performing TNE; however, TNE is still an AGP, and further mitigating strategies should be applied. LGI endoscopy produces more particles per procedure but is less particle-generating per unit of time and produces more particles in the droplet range. The main contributing events are rectal extubation, application of abdominal pressure, and rectal intubation. More studies are needed to evaluate mitigation strategies and to characterize the infectivity of these procedures themselves.

ACKNOWLEDGMENTS

We thank Guru Aithal for critically reviewing the manuscript; Martin James and Bu Hayee for reviewing the study protocol; Matthew Sanderson, Andy Wragg (Nottingham University Hospitals Research and Innovation, University of Nottingham Biomedical Research Centre), Karren Staniforth, Laura Leman, Nina Duffy, Allison Ball, and the Endoscopy Unit staff for their support of the development of this study; the NIHR Aerosol Generating Procedures Group for their support during the study; Tina Rodriguez, Paul Brocklebank, Mirela Pana, Sabina Beg, Stefano Sansone, James Catton, Emilie Wilkes, Lorraine Clark, Andrew Horton, John White, Suresh Vasan Venkatachalapathy, Aida Jawhari, Ioannis Varmpompitis, and Muthuram Rajaram for performing endoscopic procedures in this study; and Olympus for loan of the transnasal endoscopes.

Data associated with this publication are available at https://doi.org/10.17639/nott.7112. The code used for data analysis in this publication can be found at https://github.com/gsdgordon/aerosols.

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Abbreviations: AGP, aerosol-generating procedure; BMI, body mass index; COVID-19, coronavirus disease 2019; LGI, lower GI; POG, peroral gastroscopy; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; TNE, transnasal endoscopy; UGI, upper GI.

DISCLOSURE: *The following author received research support for this study from a UKRI Future Leaders Fellowship (MR/T041951/1): G. S. D. Gordon. All other authors disclosed no financial relationships. All authors acknowledge research support provided by Nottingham University Hospitals NHS Trust (funding for rental of the N60 spray characterizer and rental of a particle counter), Norgine Pharmaceuticals (sponsoring the purchase of a particle counter), and Olympus Medical UK (providing the endoscopes for transnasal endoscopy).*

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0016-5107/$36.00
https://doi.org/10.1016/j.gie.2022.05.018

Received November 14, 2021. Accepted May 24, 2022.

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