Rhinological procedures result in minimal generation of aerosols*

Enni Sanmark[1,2], Lotta-Maria Ah Oksanen[1,2], Noora Rantanen[1,2], Paula Virkkula[1,2], Ahmed Geneid[1,2]

[1] University of Helsinki, Faculty of Medicine, Helsinki, Finland

[2] Helsinki University Hospital, Department of Otorhinolaryngology and Phoniatrics – Head and Neck Surgery, Helsinki, Finland

Rhinology 61: 2, 170 - 179, 2023

https://doi.org/10.4193/Rhin22.108

***Received for publication:**

March 1, 2022

Accepted: January 8, 2023

Abstract

Background: COVID-19 and other respiratory infections spread through aerosols produced in respiratory activities and in certain surgical procedures considered as aerosol-generating procedures (AGP). Due to manipulation of the upper airway mucosa, rhinosurgery has been considered a particular risk for spread of respiratory infections. Our aim was to assess staff exposure to aerosols during common rhinosurgical procedures

Methods: Staff exposure to generated particle concentrations and size distributions between 0.3 µm and 10 µm were measured during rhinosurgery using an optical particle sizer without any additional collection methods. Similarly measured aerosol exposure during coughing (a commonly used risk reference for aerosol generation) and the operating room's background concentration were chosen as reference values.

Results: Altogether 16 common rhinological surgeries (septoplasties and endoscopic sinus surgery) were measured. The use of suction produced significantly lower aerosol concentration compared to coughing. Low aerosol generation was observed during injection anaesthesia of the nasal mucosa. Instrument comparison revealed that the microdebrider produced fewer aerosols than cold dissection in particles of 1-5 µm and >5 µm.

Conclusions: Common rhinosurgeries do not seem to generate as high aerosol concentration exposures as previously believed. Rather, the observed aerosol exposure is lower or similar to exposures during coughing. Therefore, the classification of common rhinosurgeries as AGPs should be re-assessed or possibly discarded.

Key words: COVID-19, airborne transmission, aerosol generation, microdebrider, septoplasty, endoscopic middle meatal antrostomy, maxillary antrostomy, endoscopic sinus surgery, chronic sinusitis, nasal polyp, inflammatory disease

Introduction

The COVID-19 pandemic has sparked debate about airborne transmission of pathogens and fundamentally shifted the understanding of aerosol generation as an everyday phenomenon. Aerosols are produced during all respiratory activities, including breathing, coughing, and talking [(1)]. Certain surgical procedures are associated with increased risk of airborne transmission [(2-4)]. During surgery, risk for airborne spread exists when the procedure is performed in an area where pathogens exist and aerosolizing instruments release pathogens from the tissue into the air [(5,6)]. Significant aerosol generation is associated with use of electronic medical devices and tissue removal [(7)]. SARS-CoV-2 and other respiratory viruses with airborne transmission capacity are particularly detected in the mucosa of the upper respiratory tract [(6,8)]. Accordingly, it is not surprising that rhinological procedures are regarded as risk procedures in the context of airborne transmission of respiratory diseases [(9,10)].

Among rhinological procedures, all intranasal operations are classified as high-risk aerosol-generating procedures (AGP), and only urgent intranasal surgeries have been recommended to be performed during the COVID-19 pandemic [(11)]. Risk is particularly associated with tissue removal [(7,12)]. The guidance and list of AGPs are generally not based on measured aerosol concentrati-

ons but only on common expectations [9,12]. Over the past year, several studies with varying methods have attempted to measure which rhinological procedures significantly generate aerosols. In most of these studies, nasal endoscopy has not been found to generate significant aerosol concentrations, while electrocautery and drilling have been classified as AGPs. Observations on the role of suction and microdebrider in aerosol generation are divided and no consensus exists [7,13-20].

Airborne transmission occurs via aerosol particles. Aerosol particles < 5 µm carry most (> 80%) pathogens [21-26] and their generation during rhinosurgeries are the focus of this study. At present, the relative risk of aerosol generation can be assessed by comparing the concentration of aerosols released with the concentration released during cough. If the concentration of aerosols generated by the procedure or activity is greater than coughing, the procedure or activity is considered a high-risk AGP that exceeds the aerosol generation risk during normal patient contact [3,27,28].

The primary aim of our study was to determine the exposure of operating room (OR) staff to aerosol particles that potentially carry pathogens during common rhinosurgeries and to assess aerosol generation between different instruments. Based on earlier findings by our research group, we hypothesized that the use of microdebrider, suction, or cold dissection do not generate significant aerosol concentrations [7], and use of electrocautery and other powered instruments generate significant aerosol concentrations [12]. Our secondary aim was to determine whether the nature of the rhinological disease (e.g., inflammatory disease, polyps, pus) or the form of anaesthesia (general anaesthesia, local anaesthesia) influenced aerosol production during rhinosurgery.

Materials and methods

Patients

We measured and analysed the aerosol concentration and size distribution during common rhinosurgeries performed on adults (≥ 18 years old) in Helsinki University Hospital, Department of Otorhinolaryngology and Phoniatrics – Head and Neck Surgery between August and December 2020. Surgeries were performed in normal ORs for patients who underwent either local or general anaesthesia.

This study was conducted in accordance with the ethical standards of the institutional research committee and the 1964 Declaration of Helsinki and its later amendments. The Ethics Committee of Helsinki University Hospital approved the study protocol (HUS/1701/2020). All patients provided written informed consent prior to participation.

Performed procedures

Topical anaesthesia was applied with five pledges or three cotton swabs per side both in patients operated with general and local anaesthesia. Injection anaesthesia was used after topical anaesthesia for septal incision site/columella region and for infraorbital nerve anaesthesia in septoplasty. Injection anaesthesia for endoscopic sinus surgery (ESS) was applied after topical anaesthesia into the mucosa of middle turbinate attachment and uncinate process. Endoscopic middle meatal antrostomy and partial ethmoidectomy were performed using cold dissection (seeker, biters, Weil-Blakesley forceps), microdebrider (Metronic plc, USA), or both. Septoplasties were performed using only cold dissection (specula, scalpel, septum elevator, forceps, scissors, chisel, needle holder). All these surgeries included the use of cold dissection and suction with maximal pressure (100 kPa) and microbial filters were exchanged daily (Basic surgical suction pump, Medela, USA; Bacterial/Viral filter, GVS Filter Technology UK Ltd/ GVS, Italy). Suction was used when needed with reusable or disposable suction tips (Unomedical suction handle, ConvaTec group plc, England). In addition, some surgeries included use of bipolar electrocautery, monopolar needle (bipolar electrocautery and monopolar needle combined to the group: electrocautery), radio frequency thermal ablation (RFA), drill, or different combinations thereof. The number of measurements (n=1) for drilling and RFA was small and statistical analyses could not be reliably performed. Cold dissection was used in opening of a sphenoid sinus with fungus ball. Excision of inverted papilloma with an uncinate process attachment was performed using a microdebrider, and a monopolar needle was used to excise the attachment from the healthy mucosa. Microdebrider burr and blades were used in endoscopic opening of the frontal sinus (Draf 3), and monopolar incisions were performed for mucosal flaps. During surgeries, accurate notes of all surgical steps were taken by the same research assistant.

As this study combined aerosol physics and medicine in a novel way, power calculators were not available. In previous studies with a similar design, the duration of single measurements was between 0.5 and 5 minutes and measurements were repeated 0 to 14 times. The total time measured in earlier studies varied from 2 to 157 minutes. We measured altogether 994.50 minutes in this study, which can be considered adequate compared to previous studies [7,16,20,27,29,30].

Measurements

Continuous particle measurement throughout the studied surgeries was performed with an Optical Particle Sizer (TSI model 3330) (OPS). The measurement principle of the device is based on optical light scattering from the particles (Figure 1A) and measures both particle concentration and size distribution between 0.3 µm and 10 µm every 10 seconds in 16 size bins. The

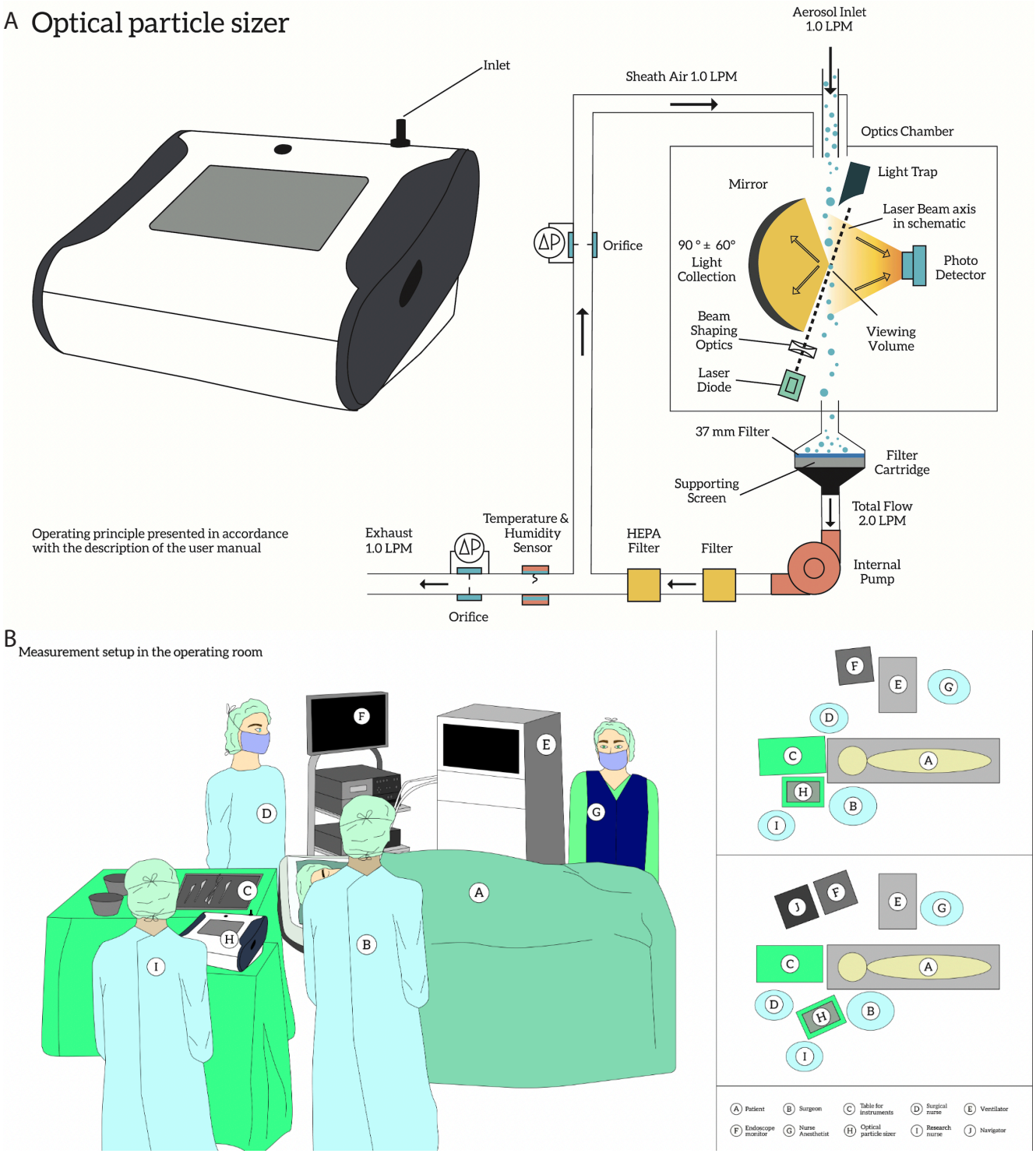

Figure 1. Schematics of the OPS operational principle (A) and operating room setups (two examples) (B).

size bins were calibrated with polystyrene latex particles with a refractive index of 1.59. The OPS had a 1 l/min flow rate and was compared with a mass flow meter (TSI model 4143). The OPS was situated on average 110 cm from the head of the patient (range 70-210 cm), as close to the surgeon or the OR nurse as the situation allowed without causing interference to the operation (Figure 1). As the study protocol was designed to reflect the exposure received by the operational staff, any additional collection methods (such as funnels) were not used (Figure 1B).

Primary and secondary analyses

Primary analyses were performed for the following instruments:

- Suction
- Microdebrider

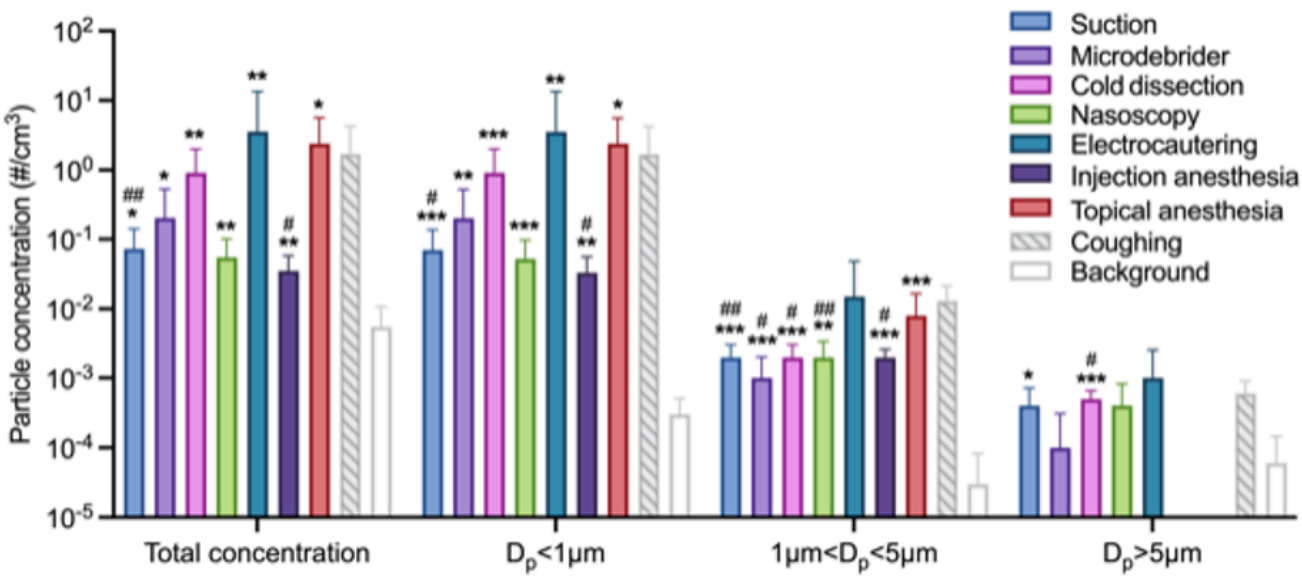

Figure 2. Particle concentrations in rhinological procedures and their comparison with background and coughing data. Mean ± SD were calculated from all measured values. Measured minimum value in all rhinological procedures and reference measurements in all size groups of particles was 0.000. Background values are presented from all operation rooms where procedures took place. For each procedure type, background was tested separately according to operation room used. Particle concentrations were compared with the background and coughing references using two-way ANOVA with Tukey HSD post-hoc test for multiple comparisons. Prior analysis data were log10 normalized. p-values < 0.05 were considered significant and significant values are marked as follows: comparisons to background *< 0.05, **< 0.01, ***p< 0.001, comparisons to coughing # < 0.05, ## < 0.01, ### < 0.001. Mean differences with 95% confidence intervals are presented in Supplemental Table 1. Inflammation, form of anaesthesia (general/local), pus, and polyps are adjusted in analysis. Total duration describes the total particle recording time. Effects of location and surgery instruments on aerosol concentrations were calculated using two-way ANOVA with Tukey HSD post-hoc test for multiple comparisons. Bipolar electrocautery and monopolar where needle were combined to the electrocautering group. SD, standard deviation.

- Cold dissection
- Nasoscopy
- Electrocautering (including bipolar electrocautery and monopolar needle)
- Topical anaesthesia
- Injection anaesthesia

The primary analyses compared the studied instruments and anaesthesia methods to the background aerosol levels and to the cough reference aerosol levels to determine

- if the procedure generates aerosols at all, and
- if the generated aerosol concentrations are significantly higher than what healthcare workers encounter during everyday patient care (cough reference).

Secondary analyses assessed the influence of the patient or infection factors on aerosol generation for the studied instruments. Factors included inflammatory disease, pus secretion during the procedure, existence of polyps, and use of local anaesthesia instead of general anaesthesia for the operation. Patients were categorized to the inflammatory group if they had chronic rhinosinusitis ± polyps (CRSwNP/CRSsNP) or had perennial allergic rhinitis requiring turbinate procedures.

Secondary analyses also assessed if aerosol generation was significantly different between the following instruments and anaesthesia methods:

- Cold dissection vs. Microdebrider
- Suction vs. Microdebrider
- Topical vs injection anaesthesia (no needle or with needle)

We also assessed if the aerosol generation was significantly different between instruments (cold dissection, suction, microdebrider) in the same surgeries (DJD20 and DMB20).

Reference measures

Background aerosol size distribution and concentrations were measured with the same OPS device in the same, empty ORs, for each OR separately following the same protocol described above. The total (mean ± standard deviation [SD]) background aerosol concentration was 0.0055±0.005 #/cm^3 (< 1 µm particles: 0.0003±0.0002, 1-5 µm particles: 0.00003±0.00005, > 5 µm particles: 0.00006±0.00008). In the measured ORs, the ventilation system (Recair 4C; ETS Nord, Tuusula, Finland) generated between 30.23 to 60.67 air changes per hour. In the laminar area, where the surgeries are performed, there were 363.35 to 572.83 air changes per hour. This means that the whole air volume of the

Table 1. Patient characteristics and measured rhinological procedures.

	All, n=16	Inflammatory disease, n=10	Non-inflammatory disease, n=6
Females, n (%)	3 (18.8%)	3 (30.0%)	0 (0.0%)
Age, years, mean (range)	51.1 (24-73)	49.1 (24-67)	54.3 (30-73)
BMI, kg/m^2, mean (range)	27.4 (21.1-36.4)	27.6 (21.1-36.4)	27.0 (23.1-32.7)
Pus secretion during the procedure, n	4	4	0
Polyps, n	2	2	0
Form of anaesthesia - General anaesthesia - Local anaesthesia	 9 7	 5 5	 4 2
Procedure(s) done/diagnosis (ICD-code)		Endoscopic opening of frontal sinus (Draf 3)/Chronic frontal sinusitis (J32.1), n=1 Midde meatal antrostomy ± partial ethmoidectomy/Chronic maxillary sinusitis (j32.0), n=5 Middle meatal antrostomy with polypectomy/partial ethmoidectomy Nasal polyposis (j33.0 and J33.8), n=2 Endoscopic sphenotomy/Chronic sphenoidal sinusitis (j32.3), n=1 Septoplasty, lateralisation and radiofrequency ablation of inferior turbinates/ Deviated nasal septum and hypertrophy of inferior turbinates and allergic rhinitis (J34.2, J34.3, J30.10), n=1.	Excision of lesion of uncinate process /Benign tumour of the nasal cavity (D14.0&), n=1 Septoplasty/Deviated nasal septum (J34.2), n=5

laminar area changes every 6 to 10 seconds.

To evaluate the risk of aerosol generation compared to respiratory activities, we used previously measured and reported particle concentrations and size distributions during coughing measured with the same method in the same ORs [7,27,31]. Coughing is commonly considered a high-risk aerosol-generating activity [3,32]. Thus, by comparing with coughing, it is possible to assess whether the procedure is safer, equal, or more dangerous than cough in terms of aerosol production. For the coughing reference, altogether 306 coughs were measured from 37 healthy volunteers between December 2020 and February 2021 at distances of 40, 70, and 100 cm with the same OPS device used in this study [31]. In cough measurements, the OPS was located perpendicular to the volunteer's face to mimic a normal treatment situation. Similarly, during rhinological procedures, OPS was positioned to mimic a normal OR situation next to the operator (Figure 1).

Statistics

The measured data were quality checked and evaluated manually. A total of four measurements were excluded from the analyses due to measurement technical disturbances. The size-dependent aerosol concentrations measured with OPS were normalized with respect to the sizing bin widths to range from 0.3 to 10 µm. The volume-weighted particle size distribution and total particle concentrations per cm^3 were calculated. The particles were categorized based on diameter (< 1 µm, 1-5 µm, and > 5 µm). Mean with SD was chosen as statistically representative to describe average aerosol exposure during the examined procedure. Parametric tests were used for hypothesis testing with log-transformed data. Differences in aerosol concentrations between different groups of patients and different techniques and instruments were analysed using two-way analysis of variance (ANOVA) with Tukey HSD post-hoc test for multiple comparisons. Prior analysis data was log10 normalized [33]. The analyses were performed with RStudio version 1.3.959 (R Foundation for Statistical Computing, Vienna, Austria) or GraphPad Prism version 9.0.2 for Mac (GraphPad Software, San Diego, CA, USA). A p-value < 0.05 was considered significant.

Results

Sixteen patients who underwent a rhinosurgery were included. Nine surgeries were performed under general anaesthesia and seven under local anaesthesia. Patients were divided into two groups based on the nature of the disease (inflammatory and non-inflammatory); pus secretion during the procedure and existence of polyps were also recorded. Patient characteristics and clinical data are presented in Table 1.

The effect of used instruments on aerosol generation

The generated particle concentrations when using different

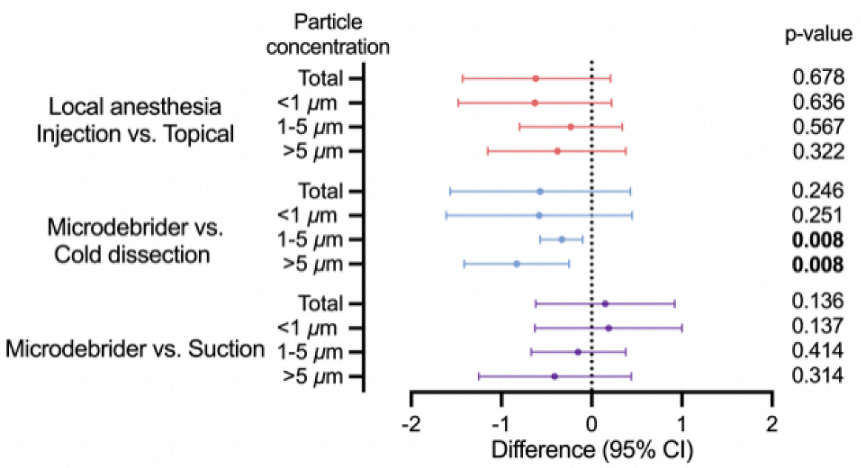

Figure 3. Pairwise comparisons of aerosol concentrations observed during use of different instruments. Results from two-way ANOVA post-hoc Tukey HSD test for multiple pairwise comparisons. Difference describes the difference between the means (log10) of the groups followed by the 95% confidence interval. Differences between instruments were adjusted by pus, inflammatory, polyps, and form of anaesthesia (local vs general). Calculations were performed with RStudio version 1.3.959 (R Foundation for Statistical Computing, Vienna, Austria) for log10-transformed particle concentrations. CI, confidence interval.

instruments were compared to background and coughing (Figure 2). All background concentrations were very low, which allowed accurate evaluation of particle generation. Drilling and radiofrequency ablation were not analysed due to use in only a single procedure or short measurement time. Use of monopolar needle was combined with bipolar electrocautery (electrocautering).

Aerosol generation comparison between different instruments

In the secondary analyses we compared aerosol generation between procedures. Results are presented in Figure 3.

Additionally, we compared particle concentrations generated during endoscopic opening of maxillary antrum (DMB20, n=4) and septoplasty (DJD20, n=4) to determine whether operation location influenced aerosol generation in the studied instruments. We found no difference in particle generation in any size range when compared with use of suction (total mean particle concentration, p = 0.853) or cold dissection (p = 0.279). We also compared cold dissection and microdebrider during the endoscopic opening of maxillary antrum (DMB20, n=4). No significant difference in size ranges was observed between cold dissection and microdebrider (p = 0.210).

Effect of patient-specific factors and form of anaesthesia on aerosol generation

Aerosol generation in different instruments was analysed according to patient factors (inflammation, pus secretion, and polyps) and form of anaesthesia (local and general) for each instrument. When the patient had no pus secretion, the use of electrocautery generated significantly higher amounts of aerosols (p = 0.017). The use of electrocautery was also associated with higher aerosol generation if the procedure was performed under general anaesthesia when compared with local anaesthesia (p = 0.018). No other statistically significant findings were observed.

We also analysed whether any patient factor (inflammation, pus secretion, polyps) or form of anaesthesia influenced aerosol generation when the use of instruments and other patient factors were adjusted. No differences were observed when comparing general anaesthesia and local anaesthesia operations (total mean concentration, p = 0.072). However, whether the patient had an inflammatory or non-inflammatory disease had an independent effect on aerosol generation in 1-5 µm (p = 0.004) and >5 µm (p= 0.010) particles. Aerosol generation was higher in patients with non-inflammatory disease. On the other hand, polyps or the pus detected during surgery did not independently affect the amount of aerosol generated in any size range.

An example timeline of A) maxillary anthrostomy and partial ethmoidectomy and B) septoplasty with presented momentary aerosol concentrations and used instruments is shown in Figure 4 and Figure 5.

Discussion

In this study we observed that rhinological procedures are not as highly aerosol generating and do not expose the OR staff to excessively high aerosol concentrations as previously believed. We measured the aerosol generation of suction, microdebrider, cold dissection, electrocautery, nasoscopy, injection anaesthesia, and topical anaesthesia and observed that none of the

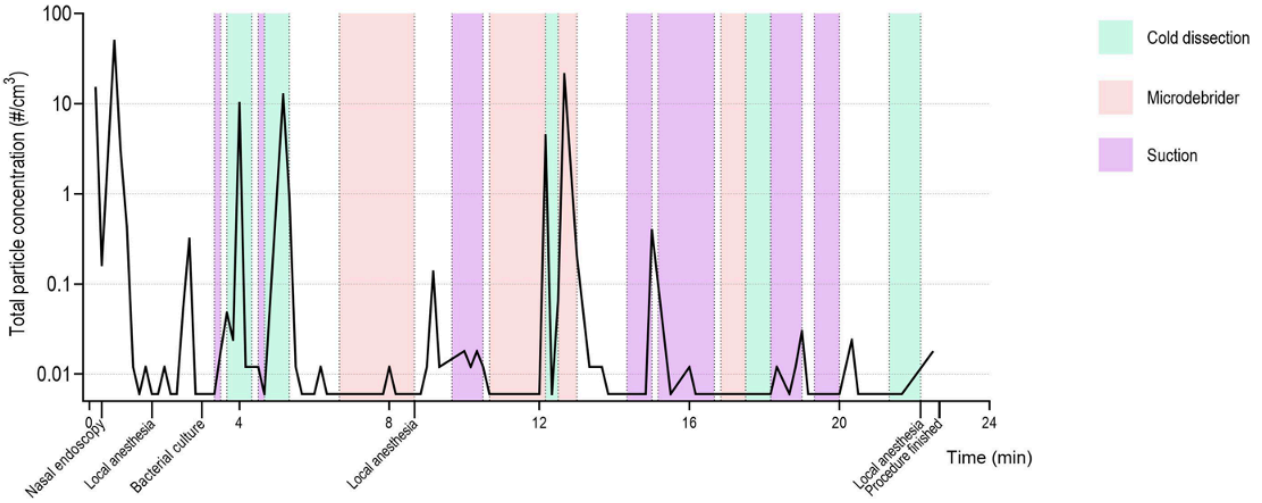

Figure 4. Example timeline of maxillary anthrostomy and partial ethmoidectomy presenting total particle concentrations throughout the surgery on logarithmic scale. Topical anaesthesia was applied 30 minutes before actual procedure.

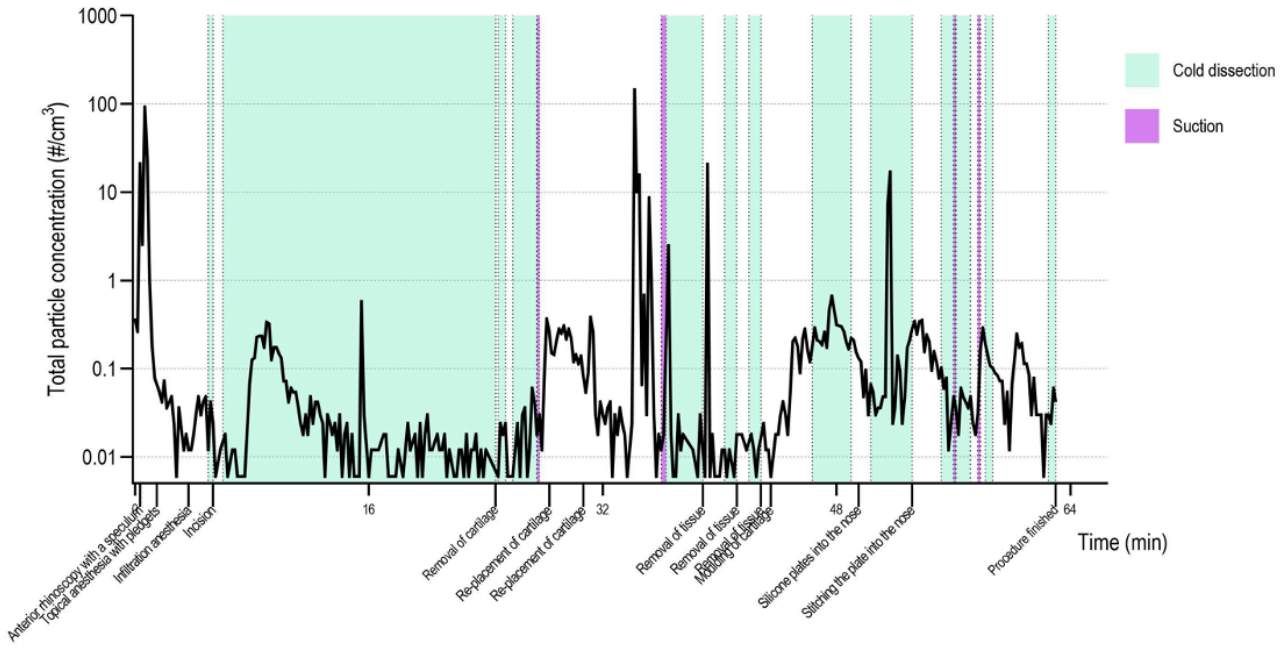

Figure 5. Example timeline of septoplasty presenting total particle concentrations throughout the surgery on logarithmic scale.

studied instruments produced higher total aerosol exposure compared to coughing. Noticeably, suction produced significantly lower aerosol concentrations. Pairwise comparison of instruments revealed that the use of microdebrider produced statistically similar aerosol concentrations as suction and significantly lower aerosol concentrations in particles 1-5 µm and >5 µm than cold dissection. The highest mean concentrations were observed when electrocautery was used, which was expected. Our findings suggest that these common rhinosurgeries are not risk operations regarding aerosol generation, especially if electrocautery is not used.

Although it has long been known that respiratory infections spread via airborne particles (i.e. aerosols), no quantitative limit values have been established for critical exposure levels. Both WHO and previous studies have used coughing as the cut-off value for significant aerosol production, which we also used in this study [3,7,27,28,32,34]. The use of cough is justified as it is a part of normal respiratory activities encountered frequently in everyday patient contacts and is associated with infection risk. To rationalize greater personal protective equipment (PPE) use for

only certain medical procedures, this everyday exposure should be surpassed. By comparing the background, we identified whether the procedure generates aerosol particles and we graded the risk by comparing the procedure with coughing. Since most pathogens spread in particles < 5 µm, we measured the concentration of small particles (0.3 -10 µm particles) [35].

Use of microdebrider has been regarded as an AGP and thus the use of microdebrider has been avoided during the COVID-19 pandemic [36]. However, the evidence for aerosol generation by a microdebrider is weak and controversial. Workman et al. did not observe production of 1 - 10 µm particles in cadaveric endonasal surgery [20]. On the other hand, Murr et al. observed in real-life patient measures increased aerosol concentrations during debridement with suction and cold instruments [16]. Although Sharma et al. observed in real-life measurements some aerosol peaks during FESS, these were not associated with microdebrider but use of cold instruments [14]. Our results are consistent with Murr et al. and Sharma et al.; we observed an increase in particle concentration compared to background during both cold dissection and microdebrider use but the generated aerosol concentration did not exceed that of coughing. Similar to Workman et al., we also observed that all procedures generated mainly 0.3 - 1 µm particles, which was the most significant size class that influenced total particle concentration in all our measurements [20].

Although microdebrider is powered instrument, the observed aerosol generation during its use was low. The low aerosol generation is probably associated with the integrated simultaneous suction during powered tissue removal. In many studies, suction reduces the number of small particles in air [30,37]. Similar results were observed in our previous studies; combining suction with the instruments used reduces the number of aerosol particles [7]. The findings of this study further support this, as there was no statistical difference in aerosol concentrations when comparing microdebrider and suction.

Cold dissection has been mainly examined in cadavers. Workman et al. did not observe an increase in the concentration of 1 - 10 µm particles [20]. In contrast, both Sharma et al. and Murr et al. reported a significant increase especially in small (<1 µm) particles during cadaveric endonasal surgery [14,16,30]. In a recent real-life study, Sharma et al. analysed the aerosol concentrations during three septoplasty surgeries and did not observe significant aerosol peaks during operation [14]. In our observations, cold dissection caused a significant increase of particle concentration, especially in small particles (< 1 µm) compared to background. Considering the significant role of small particles in both the total number of particles and the spread of disease, cold dissection should not be regarded as high risk for infection and should not be listed as a high-risk procedure based on current knowledge. However, further research is needed about the role of larger particles in the airborne transmission.

Similar to the previous literature, we did not observe a significant increase in aerosol concentration during nasoscopy [14,16-19,30]. Instead, we observed relatively high aerosol concentrations when using electrocautery, which is consistent with earlier results [10,29]. However, our sample size for electrocautering was small. Whether the lack of a statistical difference is due to the small sample size or the fact that the narrow structures of the nose reduce aerosol release cannot be determined from our data and requires further investigation.

All previous studies have focused solely on instrumentation. We wanted to investigate whether the patient's diseases (inflammatory vs. non-inflammatory) should be considered when assessing the risk of aerosol generation during the procedure. We found that a non-inflammatory disease causes significantly more aerosol release in medium (1-5 µm) and larger (>5 µm) particles compared to an inflammatory disease. The finding is consistent with the view of medicine and aerosol physics; inflammation is generally associated with fluid accumulation in tissues because of the increase in blood-vessel permeability [38,39]. An inflammatory condition implies greater humidity of tissues, which renders separation of particles less evident than in dry tissues. This was also observed in patients with no pus secretion; electrocautery generated significantly higher amounts of aerosols ($p = 0.017$). We did not find a statistical difference between local and general anaesthesia. This finding suggests that patient respiration during local anaesthesia is not an increased risk for aerosol generation when compared with general anaesthesia, which consists of a closed respiratory circuit and air filtration. This was an encouraging result, as local anaesthesia is safer and more affordable for the patient than general anaesthesia. In our material, none of the patients coughed during the procedure. However, coughing is possible during local anaesthesia and this can cause significant exposure to aerosols [31].

The probability of viral infection is described mainly using the term quanta or infection quanta, which is a mathematical model for exposure and is defined as the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons [40,41]. Coughing is a heterogeneous activity, and thus defining a direct limit to the risk caused by coughing is difficult [42]. In addition, exposure time has a significant effect on the risk of transmission. However, using quanta, it has been estimated that speaking and breathing by mouth poses a highly increased risk of exposure compared to normal resting breathing [40]. Other works have demonstrated that coughing combined with a 2-hour exposure time may pose a significant risk of infection and a cough coming straight at target can predispose to infec-

tion even in a short time frame [21,43].

There are no published studies on the transmission of COVID-19 in the OR or, more specifically, in the ear, nose, and throat OR. In contrast, several studies have been published on the spread of COVID-19 in hospitals. However, even these do not reveal infections related to the OR, but rather the chains of infection in the emergency room and wards [44-46].

The purpose of this study was to measure aerosol exposure to personnel during rhinosurgeries. Therefore, the measurements were performed in a real OR environment. The use of real patients instead of cadavers provide more realistic results. The OPS was always placed close the operator and assistant nurse or surgeon without interfering with the ongoing surgery. Because of the nature of the methodology, we could not measure the total generated aerosol concentration but aerosol exposure at one point in the OR. Another limitation is the very limited number of patients who had drilling and radiofrequency ablation; these data were not analysed. Aerosol production is associated with various non-medical activities, such as speaking and breathing [47]. However, in our study, all staff used masks throughout the surgeries, which efficiently reduces aerosol release [48,49]. This can be seen also in our study; there were several measurements with 0 particles/cm^3 even though the staff was breathing continually. This indicates that staff respiratory activities do not cause significant bias in our study.

Conclusion

Rhinosurgeries do not release as high aerosol concentrations as previously believed and therefore should not be classified as AGPs. Microdebrider, cold dissection, and nasal endoscopy generated smaller mean aerosol concentrations than coughing. The use of suction produced statistically lower aerosol concentrations than coughing. The aerosol concentration between suction and microdebrider was also statistically similar. Local anaesthesia with normal, unfiltered patient breathing did not increase aerosol generation in our patients. Tissue factors, such as inflammation or its absence, may influence aerosol generation, a subject previously unexplored. Continuous suction close to the nostrils combined with all sinonasal procedures may be an efficient and cost-effective means to reduce aerosol exposure in rhinosurgery.

Authorship contribution

ES: conception. resources, study design, search, study selection, data collection, data analysis, drafting the articles. NR: study selection, data collection, data analysis, drafting the articles. LO: conception, study design, search, study selection, critical revision of the article. ATM: critical revision of the article. RM: conception, study design, critical revision of the article. AG: conception, resources, study design, critical revision of the article. All authors approved the final version to be published.

Acknowledgement

We thank research nurse Ms. Catharina Pomoell for her contributions to the study and the entire staff of Helsinki University Hospital, Department of Otorhinolaryngology and Phoniatrics – Head and Neck Surgery for assistance in conducting the study. We thank all the participating patients who made this study possible. In addition, we thank Tero Vahlbeg for statistical analysis.

Conflict of interest

None of the authors have any financial or other relationship that might lead to conflict of interests.

Funding

This work was supported by the Helsinki University Hospital Research Fund, Finska Läkaresällskapet (ES), the Jalmari and Rauha Ahokas foundation (ES), the Foundation of the Finnish Anti-Tuberculosis Association, and the Paulo Foundation.

References

1. Murbe D, Kriegel M, Lange J, Schumann L, Hartmann A, Fleischer M. Aerosol emission of adolescents voices during speaking, singing and shouting. PLoS One. 2021; 16(2): e0246819.
2. Hamilton F, Arnold D, Bzdek BR, et al. Aerosol generating procedures: are they of relevance for transmission of SARS-CoV-2? Lancet Respir Med. 2021; 9(7): 687-689.
3. Brown J, Gregson FKA, Shrimpton A, et al. A quantitative evaluation of aerosol generation during tracheal intubation and extubation. Anaesthesia. 2021; 76(2): 174-181.
4. Ofner M, Lem M, Sarwal S, Vearncombe M, Simor A. Cluster of severe acute respiratory syndrome cases among protected health care workers-Toronto, April 2003. Can Commun Dis Rep. 2003; 29(11): 93-97.
5. Granados A, Peci A, McGeer A, Gubbay JB. Influenza and rhinovirus viral load and disease severity in upper respiratory tract infections. J Clin Virol. 2017; 86: 14-19.
6. Zou L, Ruan F, Huang M, et al. SARS-CoV-2 Viral Load in Upper Respiratory Specimens of Infected Patients. N Engl J Med. 2020; 382(12): 1177-1179.
7. Sanmark E, Oksanen LAH, Rantanen N, et al. Microdebrider is less aerosol-generating than CO2 laser and cold instruments in microlaryngoscopy. Eur Arch Otorhinolaryngol. 2022;279(2):825-834.
8. Penarrubia L, Ruiz M, Porco R, et al. Multiple assays in a real-time RT-PCR SARS-CoV-2 panel can mitigate the risk of loss of sensitivity by new genomic variants during the COVID-19 outbreak. Int J Infect Dis. 2020; 97: 225-229.
9. Lagos AE, Ramos PH, Andrade T. Protection for Otolaryngologic Surgery in the COVID-19 Pandemic. OTO Open. 2020; 4(2): 2473974X20934734.
10. Kowalski LP, Sanabria A, Ridge JA, et al. COVID-19 pandemic: Effects and evidence-based recommendations for otolaryngology and head and neck surgery practice. Head Neck. 2020; 42(6): 1259-1267.
11. Givi B, Schiff BA, Chinn SB, et al. Safety Recommendations for Evaluation and Surgery of the Head and Neck During the COVID-19 Pandemic. JAMA Otolaryngol

Head Neck Surg. 2020; 146(6): 579-584.
12. Mick P, Murphy R. Aerosol-generating otolaryngology procedures and the need for enhanced PPE during the COVID-19 pandemic: a literature review. J Otolaryngol Head Neck Surg. 2020; 49(1): 29.
13. Dhillon RS, Nguyen LV, Rowin WA, et al. Aerosolisation in endonasal endoscopic pituitary surgery. Pituitary. 2021.
14. Sharma D, Campiti VJ, Ye MJ, et al. Aerosol generation during routine rhinologic surgeries and in-office procedures. Laryngoscope Investig Otolaryngol. 2021; 6(1): 49-57.
15. Tuli IP, Trehan S, Khandelwal K, et al. Diagnostic and therapeutic endonasal rhinologic procedures generating aerosol during COVID-19 pandemic: a systematized review. Braz J Otorhinolaryngol. 2021. 87(4):469-477.
16. Murr AT, Lenze NR, Gelpi MW, et al. Quantification of Aerosol Concentrations During Endonasal Instrumentation in the Clinic Setting. Laryngoscope. 2020. 131(5):E1415-E1421.
17. Boorgu D, Dharmarajan H, Sim ES, et al. Aerosol and Droplet Risk of Common Otolaryngology Clinic Procedures. Ann Otol Rhinol Laryngol. 2021: 34894211000502.
18. Dharmarajan H, Freiser ME, Sim E, et al. Droplet and Aerosol Generation With Endonasal Surgery: Methods to Mitigate Risk During the COVID-19 Pandemic. Otolaryngol Head Neck Surg. 2021; 164(2): 285-293.
19. David AP, Jiam NT, Reither JM, Gurrola JG, 2nd, Aghi MK, El-Sayed IH. Endoscopic skull base and transoral surgery during COVID-19 pandemic: Minimizing droplet spread with negative-pressure otolaryngology viral isolation drape. Head Neck. 2020; 42(7): 1577-1582.
20. Workman AD, Jafari A, Welling DB, et al. Airborne Aerosol Generation During Endonasal Procedures in the Era of COVID-19: Risks and Recommendations. Otolaryngol Head Neck Surg. 2020; 163(3): 465-470.
21. Vuorinen V, Aarnio M, Alava M, et al. Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors. Saf Sci. 2020; 130: 104866.
22. Papineni RS, Rosenthal FS. The size distribution of droplets in the exhaled breath of healthy human subjects. J Aerosol Med. 1997; 10(2): 105-116.
23. Fennelly KP, Jones-Lopez EC, Ayakaka I, et al. Variability of infectious aerosols produced during coughing by patients with pulmonary tuberculosis. Am J Respir Crit Care Med. 2012; 186(5): 450-457.
24. Patterson B, Morrow C, Singh V, et al. Detection of Mycobacterium tuberculosis bacilli in bio-aerosols from untreated TB patients. Gates Open Res. 2017; 1: 11.
25. Lindsley WG, Blachere FM, Thewlis RE, et al. Measurements of airborne influenza virus in aerosol particles from human coughs. PLoS One. 2010; 5(11): e15100.
26. Abbey H. An examination of the Reed-Frost theory of epidemics. Hum Biol. 1952; 24(3): 201-233.
27. Oksanen LM, Sanmark E, Sofieva S, et al. Aerosol generation during general anesthesia is comparable to coughing: An observational clinical study. Acta Anaesthesiol Scand. 2021; 66(4):463-472.
28. Yang S, Lee GW, Chen CM, Wu CC, Yu KP. The size and concentration of droplets generated by coughing in human subjects. J Aerosol Med. 2007; 20(4): 484-494.
29. Guderian DB, Loth AG, Weiss R, Diensthuber M, Stover T, Leinung M. In vitro comparison of surgical techniques in times of the SARS-CoV-2 pandemic: electrocautery generates more droplets and aerosol than laser surgery or drilling. Eur Arch Otorhinolaryngol. 2021; 278(4): 1237-1245.
30. Sharma D, Ye MJ, Campiti VJ, et al. Mitigation of Aerosols Generated During Rhinologic Surgery: A Pandemic-Era Cadaveric Simulation. Otolaryngol Head Neck Surg. 2021; 164(2): 433-442.
31. Sanmark E OLA, Rantanen N, Lahelma M, Anttila V-J, Lehtonen L, Hyvärinen A-P, Geneid A. Aerosol Generation during Coughing – An observational study. MedrXiv. 2021.
32. Organization WH. Infection prevention and control during health care when coronavirus disease (COVID-19) is suspected or confirmed 2020 [cited 2, 2020 June 29, 2020].
33. Heintzenberg J. Properties of the log-normal particle size distribution. Aerosol Sci Technol. 1994; 21(1): 46-48.
34. Jackson T, Deibert D, Wyatt G, et al. Classification of aerosol-generating procedures: a rapid systematic review. BMJ Open Respir Res. 2020; 7(1).
35. Coleman KK, Tay DJW, Sen Tan K, et al. Viral Load of SARS-CoV-2 in Respiratory Aerosols Emitted by COVID-19 Patients while Breathing, Talking, and Singing. Clin Infect Dis. 2021.
36. Wilson J, Carson G, Fitzgerald S, et al. Are medical procedures that induce coughing or involve respiratory suctioning associated with increased generation of aerosols and risk of SARS-CoV-2 infection? A rapid systematic review. J Hosp Infect. 2021; 116: 37-46.
37. Broderick D, Kyzas P, Sanders K, Sawyerr A, Katre C, Vassiliou L. Surgical tracheostomies in Covid-19 patients: important considerations and the "5Ts" of safety. Br J Oral Maxillofac Surg. 2020; 58(5): 585-589.
38. Orr Jr C HF, Corbett WJ. Aerosol size and relative humidity. J Colloid Sci. 1958; 13(5): 472-482.
39. Walker JE WJR, Merrill E, Mcquiston WO. Heat and Water Exchange in the Respiratory Tract. Surv Anesthesiol. 1962; 6(3): 256-259.
40. Buonanno G, Stabile L, Morawska L. Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. Environ Int. 2020; 141: 105794.
41. Wells WF. Airborne Contagion and Air Hygiene: An Ecological Study of Droplet Infections. Harvard University Press. 1955.
42. Mazzone SB, Farrell MJ. Heterogeneity of cough neurobiology: Clinical implications. Pulm Pharmacol Ther. 2019; 55: 62-66.
43. Schijven J, Vermeulen LC, Swart A, Meijer A, Duizer E, de Roda Husman AM. Erratum: Quantitative Microbial Risk Assessment for Airborne Transmission of SARS-CoV-2 via Breathing, Speaking, Singing, Coughing, and Sneezing. Environ Health Perspect. 2021; 129(9): 99001.
44. Zhan M, Qin Y, Xue X, Zhu S. Death from Covid-19 of 23 Health Care Workers in China. N Engl J Med. 2020; 382(23): 2267-2268.
45. Rickman HM, Rampling T, Shaw K, et al. Nosocomial Transmission of Coronavirus Disease 2019: A Retrospective Study of 66 Hospital-acquired Cases in a London Teaching Hospital. Clin Infect Dis. 2021; 72(4): 690-693.
46. Heinzerling A, Stuckey MJ, Scheuer T, et al. Transmission of COVID-19 to Health Care Personnel During Exposures to a Hospitalized Patient - Solano County, California, February 2020. MMWR Morb Mortal Wkly Rep. 2020; 69(15): 472-476.
47. Chacon AM, Nguyen DD, McCabe P, Madill C. Aerosol-generating behaviours in speech pathology clinical practice: A systematic literature review. PLoS One. 2021; 16(4): e0250308.
48. Asadi S, Cappa CD, Barreda S, Wexler AS, Bouvier NM, Ristenpart WD. Efficacy of masks and face coverings in controlling outward aerosol particle emission from expiratory activities. Sci Rep. 2020; 10(1): 15665.
49. Verma S, Dhanak M, Frankenfield J. Visualizing the effectiveness of face masks in obstructing respiratory jets. Phys Fluids (1994). 2020; 32(6): 061708.

Enni Sanmark
Valhallankatu 7a 21
00250 Helsinki
Finland

Tel: +358-408446940
E-mail: enni@sanmark.fi
ORCID: 0000-0003-0209-5501

This manuscript contains online supplementary material

SUPPLEMENTARY MATERIAL

Supplemental Table 1. Aerosol concentrations when using different instrument compared to the background and coughing.

Instrument		Mean difference (95 % CI)	
		Background	Coughing
Suction			
	Total particle concentration	-0.790 (-1.378, -0.203)	0.570 (0.152, 0.988)
	< 1 μm particle concentration	-2.068 (-2.708, -1.429)	0.579 (0.146, 1.012)
	1-5 μm particle concentration	-2.003(-2.514, -1.493)	0.665 (0.228, 1.102)
	> 5 μm particle concentration	-0.838 (-1.560, -0.117)	-0.172 (-0.765, 0.422)
Microdebrider			
	Total particle concentration	-0.944 (-1.873, -0.0148)	0.416 (-0.237, 1.070)
	< 1 μm particle concentration	-2.253 (-3.280, -1.227)	0.394 (-0.281, 1.069)
	1-5 μm particle concentration	1.858 (-2.199, -1.518)	0.810 (0.137, 1.483)
	> 5 μm particle concentration	-0.429 (-1.391, 0.532)	0.237 (-0.694, 1.168)
Cold dissection			
	Total particle concentration	-1.512 (-2.385, -0.639)	-0.152 (-0.626, 0.322)
	< 1 μm particle concentration	-2.833 (-3.744, -1.923)	-0.186 (-0.674, 0.302)
	1-5 μm particle concentration	-2.191 (-2.455, -1.928)	0.477 (0.0671, 0.887)
	> 5 μm particle concentration	-1.260 (-1.702, -0.817)	-0.593 (-1.152, -0.0334)
Nasoscopy			
	Total particle concentration	-2.190 (-3.916, -0.465)	0.494 (-0.006, 0.993)
	<1 μm particle concentration	-2.590 (-4.489, -0.691)	0.485 (-0.032, 1.002)
	1-5 μm particle concentration	-0.940 (-1.967, 0.0872)	0.807 (0.219, 1.395)
	> 5 μm particle concentration	-0.506 (-1.442, 0.430)	0.161 (-0.586, 0.908)
Elecrocautering			
	Total particle concentration	-1.690 (-2.274, -1.105)	-0.329 (-1.082, 0.423)
	< 1 μm particle concentration	-2.994(-3.739, -2.249)	-0.346 (-1.122, 0.430)
	1-5 μm particle concentration	-2.479 (-2.895, -2.063)	0.189 (-0.627, 1.006)
	> 5μ m particle concentration	-1.403 (-2.081, 0.724)	-0.736 (-1.838, 0.367)
Injection anaesthesia			
	Total particle concentration	-0.775 (-1.243, -0.306)	0.586 (0.134, 1.037)
	< 1μm particle concentration	-2.062 (-2.600, 1.526)	0.585 (0.118, 1.053)
	1-5 μm particle concentration	-1.995 (-2.572, -1.418)	0.674 (0.172, 1.175)
	> 5 μm particle concentration	-0.742 (-1.736, 0.253)	-0.075 (-0.779, 0.630)
Topical anaesthesia			
	Total particle concentration	-1.387 (-2.479, -0.295)	-0.027 (-0.552, 0.499)
	< 1μm particle concentration	-2.696 (-3.834, -1.557)	-0.048 (-0.591, 0.494)
	1-5μm particle concentration	-2.224 (-2.881, -1.567)	0.445 (-0.015, 0.904)
	> 5μm particle concentration	-1.123 (-1.7670, -0.476)	-0.456 (-1.039, 0.127)

Bipolar electrocautery and monopolar needle were combined to the electrocautering group. Mean difference and 95% CI were calculated from log-normalized values. CI, confidence interval.