The Journal of Laryngology & Otology

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Comparison of aerosol generation between electrocautery and cold dissection tonsillectomy

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Main Article

Dr E Sanmark takes responsibility for the integrity of the content of the paper

Cite this article: Sanmark E, Rantanen N, Oksanen L-M, Matvejeff AT, Möller R, Geneid A. Comparison of aerosol generation between electrocautery and cold dissection tonsillectomy. *J Laryngol Otol* 2023;**137**: 732–740. https://doi.org/10.1017/S0022215123000324

Accepted: 4 February 2023
First published online: 27 March 2023

Key words:
Covid-19; Airborne Transmission; Tonsillectomy; Electrocautery; Cold Dissection Technique

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Abstract

Objective. Coronavirus disease 2019 can spread through aerosols produced by surgical procedures, but knowledge of the extent of aerosol production and the risk posed by many common procedures does not exist. This study analysed aerosol generation during tonsillectomy and how it differs between distinct surgical techniques and instruments. The results can be used in risk assessment during current and future pandemics and epidemics.

Method. An optical particle sizer was used to measure particle concentrations generated during tonsillectomy from the perspectives of the surgeon and other staff. Coughing is commonly used as a reference for high-risk aerosol generation; therefore, coughing and the operating theatre's background concentration were chosen as reference values. Different instruments were also compared to find the safest way to perform the tonsillectomy from the perspective of airborne transmission.

Results. Eighteen tonsillectomies were evaluated; all techniques mostly generated less than 1 µm particles. For the surgeon, bipolar electrocautery significantly exceeded the particle generation of coughing in both total and less than 1 µm particles and was found to produce significantly higher total and less than 1 µm aerosol concentrations than cold dissection and BiZact. No technique exposed other staff to a greater aerosol concentration than is generated by a cough.

Conclusion. Bipolar electrocautery generated high aerosol concentrations during tonsillectomy; cold dissection generated significantly less. The results support cold dissection as the primary tonsillectomy technique, particularly during the epidemics of airborne diseases.

Introduction

The coronavirus disease 2019 (Covid-19) pandemic has focused general scientific interest on better understanding the aerosol transmission of pathogens.[1] Covid-19 is known to be transmitted through the air by aerosol-generating activities, such as breathing, talking and coughing.[2] Evidence also suggests that aerosols may be transmitted by certain medical procedures in the respiratory tract area and by tissue removal and the use of powered devices; electrocauterisation and laser, for example, have been viewed as a risk for significant aerosol generation.[3] Tonsillectomy, one of the most common surgical procedures in the world, is therefore assumed to generate aerosols as it is performed in the respiratory tract area and because significant amounts of tissue are removed during the procedure.

The decades-long debate about optimal surgical technique in tonsillectomy has yielded no consensus.[4,5] In determining the ideal tonsillectomy technique, the conventional cold dissection technique and the bipolar electrocautery technique have been frequently compared in the literature, and the two are also the most widely used by far.[6] Both techniques have their advantages and disadvantages, but some main findings can be stated: (1) the incidence of intra-operative bleeding is generally lower with bipolar electrocautery technique than for the cold dissection technique;[4] (2) post-operative haemorrhage is more common when using bipolar electrocautery,[7] although contradictory findings exist;[8] (3) the duration of surgery is longer when using cold dissection,[8] although some studies have showed mixed results;[9] and (4) post-surgical pain has been observed to be more intensive after bipolar electrocautery.[5] Newer devices have recently emerged alongside old technologies. BiZact™ is a bipolar 'current-carrying' device that can seal vessels through applying only the required energy levels[10]; thus, it has been termed a 'softened hot' technique.[10] When comparing the cold dissection technique and current-carrying electrocautery instruments, such as BiZact, the latter has been shown to reduce intra-operative bleeding and operative time and to reduce post-operative pain in comparison with cold dissection.[11]

Before the Covid-19 pandemic, the most important criteria for the ideal tonsillectomy technique were: (1) shorter duration, (2) reduced post-operative pain, (3) minimised possibility for peri-operative bleeding, and (4) safety and efficacy.[7] During the Covid-19 pandemic, a new criterion for tonsillectomy was identified: a safer technique in terms of

exposing operating theatre staff to aerosols. Since tonsillectomy can be performed with several different techniques and no single winning technique has been found, the risk of aerosol infection can be reduced in epidemic and pandemic situations by choosing the surgical technique that produces the fewest aerosols.

Our aims were to analyse the aerosol generation during tonsillectomy and to compare differences in aerosol generation between the cold dissection technique, bipolar electrocautery technique and BiZact™ techniques. This information is needed to support clinicians in selecting a tonsillectomy technique, especially during peaks of the Covid-19 pandemic or other future airborne epidemics in the future and brings alternatives and/or additional means for screening and personal protective equipment to reduce the risk of infection.

Materials and methods

Surgical procedures

Altogether, 18 tonsillectomies were measured in the Department of ENT Diseases, Helsinki University Hospital, between August 2020 and May 2021. All the tonsillectomies were elective surgical procedures performed on intubated patients under general anaesthesia. The surgeon excised the tonsils using a scalpel, scissors and other steel instruments (cold dissection technique) and/or an electrocautery tool that uses heat to remove the tissue and stop the bleeding (bipolar electrocautery technique or BiZact). The surgeon chose the surgical technique and was free to combine techniques, such as cold dissection technique and bipolar electrocautery technique. Therefore, the cold dissection technique was used in procedures for a shorter time than bipolar electrocautery technique on average, although, in general, the bipolar electrocautery technique has a shorter operating time.[8] Other than the use of the surgical technique, all the procedures followed the same operational protocols, including suction, which was used throughout all the tonsillectomies. All instruments used by the surgeon and all significant work steps during the surgery were registered and recorded in a log.

Particle measurements

The particle measurement was continuous during all the procedures. The tonsillectomies were measured at various distances: 40 cm from the patient, reflecting the exposure of the surgeon ($n = 8$) or 70–150 cm from the patient, reflecting the exposure encountered by the rest of the operating theatre staff ($n = 10$). In order to determine the surgeon's exposure as accurately as possible, a thick tube that collected the aerosols was attached to the surgeon's headlamp ending at the point of the surgeon's nose during the measurement. In accordance with the laws of physics, some of the largest particles remain in the tubes that are used. However, pathogens have been found to migrate in particles less than 5 µm, so the largest particles are of least importance in assessing the spread of infections.[12] No additional collection methods, such as funnels, were used when measuring the exposure of the rest of the operating theatre staff, and the distance varied from 70 cm to 150 cm. Because the study was conducted in the real environment and no additional collection methods were used in the measurement, measuring distance varied depending on the clinical situation. The measurement was always performed as close to the patient as possible, depending on the patient's treatment. All the measurements were carried out with the same optical particle sizer device, so no simultaneous measurements were made.

Measurements were conducted with a TSI model 3330 (Minnesota, USA) optical particle sizer. The online optical particle sizer measures the particle concentration as well as size distributions between 0.3 µm and 10 µm in 16 size bins every 5 to 10 seconds. The proper functioning of the optical particle sizer was validated and monitored according to the following principles: (1) the device was factory calibrated before the study; (2) the 1 l/minute flow rate was audited with a mass flow meter (TSI model 4143); (3) the sizing was examined with 900 nm polystyrene latex particles, and the size bins were calibrated using polystyrene latex particles with a refractive index of 1.59; and (4) the particle concentrations measured by the optical particle sizer used in the operating theatre were compared against another optical particle sizer device.

The ventilation rate varied between 30.23 and 60.67 air exchanges per hour in the operating theatres and between 363.35 and 572.83 per hour in the laminar ventilation area. For comparison, the American Institute of Architects recommends a minimum ventilation of 25 exchanges per hour in an operating theatre.[13] In our study, the procedures were performed in the laminar area, which enables clearance of the generated particles every 6–10 seconds. Thus, the accumulation of particles is minimal and comparison of different techniques was possible and reliable.

Control measures

Two different control measurements were employed in this study: background and coughing. Background measurements of the particle concentrations in the empty operating theatres were compared with measured aerosol generation during tonsillectomies to determine whether any aerosol particles were generated during the observed techniques. The background aerosol concentration of the operating theatres was almost 0 particles/cm^3. The background aerosol concentrations were measured with the same optical particle sizer device in the same empty operating theatres in which the surgical procedures were performed, following the same protocol that was used in tonsillectomy measurements. At present, a quantitative value for the acceptable or risky number of aerosol particles does not exist. Both the World Health Organization and previous studies have used coughing as the cut-off value for significant aerosol production, which was also used in the current study.[3,14–18] Thus, the cough measurements presented in Sanmark *et al.*[19] were used to evaluate the level of the risk of infection by comparing the aerosol concentrations measured during the tonsillectomies with cough concentrations.[19] By comparing aerosol generation with coughing during tonsillectomy, it is possible to assess whether the procedure is safer, equivalent to or more dangerous than coughing in terms of aerosol generation. For the coughing reference, 306 coughs from 37 healthy volunteers were measured at distances of 40 cm, 70 cm and 100 cm with the same optical particle sizer device used in this study. The coughing data were collected, measured and analysed using the same method as in the background and tonsillectomy measurements.[19]

Data processing

The data were quality checked, and all elements with potential sources of error were excluded. The data were combined with

https://doi.org/10.1017/S0022215123000324 Published online by Cambridge University Press

the log details, and the elements of the data that contained the use of the instruments of interest were selected for later statistical analysis. The data were divided into three categories based on the instruments used: (1) bipolar electrocautery technique, (2) cold dissection technique and (3) BiZact™. Two subgroup categories were analysed based on exposure and measuring distance: (1) surgeon and (2) the rest of the operating theatre staff. Because during the measurements we observed that the bipolar electrocautery technique produced considerable amounts of particles, in the data processing phase we excluded the first 10-second measurement from the cold dissection technique and BiZact measurements immediately after bipolar electrocautery technique, so that aerosol generation during the bipolar electrocautery technique did not affect the other results.

Statistical analysis

No existing power calculators were available. A similar design has been used in previous studies by our group and other scientists, however, and the number of patients and durations of the tonsillectomies measured in this study are in line with previous studies.[3,20–22] The data were analysed with no corrections to sizing, but the size distributions were normalised to enable presentation of the size distributions independently of the bin widths. The particles were categorized as less than 1 µm, 1–5 µm and more than 5 µm. The mean particle concentrations with standard deviation were calculated for the examined procedures. The mean was chosen as a statistically representative parameter as it describes the average exposure during an individual procedure. The lower limit of the standard deviation in all the measured procedures was 0 particles/cm^3 because of the very clean measurement environment and laminar ventilation. A linear mixed model was used for pairwise and multiple pairwise comparisons between the tonsillectomy techniques, operating theatre background and coughing references. A random intercept for patient identification was used in a linear mixed model, considering the dependence of observations measured on the same patient. Multiple pairwise comparisons were corrected using the Bonferroni method. Prior to analysis, data was transformed using a logarithm to the base 10 because of skewed distributions.[23] Statistical calculations were performed using SPSS® (version 26) statistical analysis software. *P*-values less than 0.05 were considered significant. In addition to statistical analysis, the data were manually checked for possible increase of aerosol concentration during different procedures (such as removing the tonsils).

Ethical aspects

All the procedures were 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 their participation.

Results

A total of 18 patients who underwent tonsillectomy were included in the study. The indications for tonsillectomies included chronic tonsillitis ($n = 11$), peritonsillar abscess ($n = 3$) and tonsil hyperplasia ($n = 4$). The median age of the measured patients was 29 (range, 19–44) years, 55.6 per cent were males and the mean body mass index was 26.3 (range, 19.7–37.6) kg/m^2. The average duration of the tonsillectomy was 18:36 ± 7:25 (range, 9:30–31:20) minutes.

The following techniques were used: bipolar electrocautery technique in 18 procedures, cold dissection in 15 procedures and BiZact in 2 procedures. The cold dissection technique was used for an average of 1:48 (range, 0:30–4:30) minutes, the bipolar electrocautery technique for an average of 10:03 (range, 1:00–30:50) minutes and BiZact for an average of 1:55 (range, 1:55–1:55) minutes during a tonsillectomy. Eight tonsillectomies were measured from the distance of the surgeon (surgeon exposure) and 10 from the distance of the other staff (operating theatre staff exposure) to the patient. Figure 1 shows a timeline of one measured tonsillectomy,

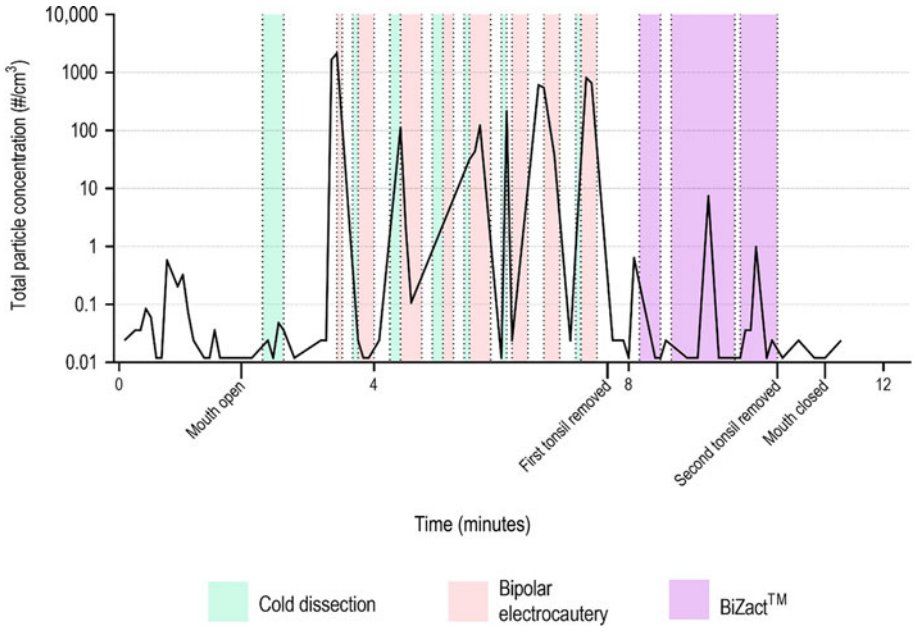

Figure 1. Timeline of one of the measured tonsillectomies with all three techniques (cold dissection, bipolar electrocautery and BiZact) showing total particle concentrations throughout the surgery on a logarithmic scale.

https://doi.org/10.1017/S0022215123000324 Published online by Cambridge University Press

Table 1. Mean and maximum particle concentrations of different tonsillectomy techniques with operating theatre background and coughing references

Parameter	Measured procedures (*n*)	Size group (µm)	Particle concentration (mean ± SD; particles/cm^3)	Particle concentration maximum (particles/cm^3)
Surgeon exposure	8			
– Bipolar electrocautery	8	Total	358.175 ± 1016.697	8694.330
		<1	358.172 ± 1016.697	8694.330
		1–5	0.003 ± 0.017	0.276
		>5	0.001 ± 0.004	0.060
– Cold dissection	7	Total	1.771 ± 8.092	63.420
		<1	1.768 ± 8.092	63.408
		1–5	0.003 ± 0.007	0.048
		>5	0.000 ± 0.002	0.012
– BiZact	2	Total	0.199 ± 1.090	7.368
		<1	0.197 ± 1.090	7.368
		1–5	0.002 ± 0.005	0.012
		>5	0.000 ± 0.000	0.000
Operating theatre staff exposure	10			
– Bipolar electrocautery	10	Total	1.303 ± 16.394	390.072
		<1	1.300 ± 16.394	390.072
		1–5	0.003 ± 0.007	0.096
		>5	0.000 ± 0.002	0.018
– Cold dissection	8	Total	1.308 ± 10.364	107.424
		<1	1.304 ± 10.364	107.424
		1–5	0.004 ± 0.007	0.042
		>5	0.000 ± 0.002	0.012
References				
– Operating theatre background		Total	0.006 ± 0.019	0.228
		<1	0.005 ± 0.019	0.228
		1–5	0.000 ± 0.002	0.018
		>5	0.000 ± 0.000	0.006
– Coughing		Total	1.601 ± 13.772	195.528
		<1	1.588 ± 13.751	195.510
		1–5	0.012 ± 0.064	1.242
		>5	0.001 ± 0.002	0.012

Mean ± standard deviation (SD) and maximum particle concentrations were calculated from all the measured time points for each tonsillectomy technique. The background reference values were measured in all operating theatres in which the tonsillectomy procedures were performed. The measured minimum value of all the tonsillectomy techniques and references in all size groups of particles was 0.000.

which included the cold dissection technique, bipolar electrocautery technique and BiZact technique with measured momentary aerosol concentrations.

All the presented tonsillectomy techniques mostly generated less than 1 µm particles. In larger size groups of 1–5 µm and more than 5 µm, observed particle concentrations were substantially lower. The average and maximum particle concentrations measured from the perspective of the surgeon and other operating theatre staff are shown in Table 1. When compared with the background reference, all the tonsillectomy techniques showed significantly higher particle concentrations in both total and small particles. In comparison to the coughing reference, only the bipolar electrocautery technique as measured from the surgeons' perspective significantly exceeded the particle generation of the coughing reference in both total and less than 1 µm particles. The results of the comparisons with background and coughing are presented in Table 2. The comparison of the exposures of the surgeon ($n = 8$) and other operating theatre staff ($n = 10$) during the bipolar electrocautery technique showed that significantly higher particle concentrations were observed from the surgeons' perspective in total concentration ($p = 0.003$) and all size groups (less than 1 µm particles, $p = 0.003$; 1–5 µm particles, $p = 0.003$; more than 5 µm particles, $p = 0.046$).

We compared the exposure from the surgeon's perspective during all three techniques (bipolar electrocautery technique, cold dissection technique and BiZact). From the perspective of other operating theatre staff, procedures that included BiZact use were not available during data collection, so only

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Table 2. Comparisons of particle concentrations in tonsillectomy procedures with operating theatre background and coughing references

Parameter	Measured procedures (*n*)	Particles (μm)	Operating theatre background (mean difference (95% CI))	*P*-value	Coughing (mean difference (95% CI))	*P*-value
Surgeon exposure	8					
– Bipolar electrocautery	8	Total	3.587 (2.647 to 4.528)	<0.001*	1.503 (0.768 to 2.238)	<0.001*
		<1	3.473 (2.539 to 0.406)	<0.001*	1.452 (0.721 to 2.182)	<0.001*
		1–5	0.338 (−0.515 to 1.191)	1	−1.266 (−1.875 to −0.577)	0.001*
		<5	0.034 (−0.290 to 0.359)	1	−0.193 (−0.441 to 0.056)	0.373
– Cold dissection	7	Total	1.962 (0.949 to 2.975)	<0.001*	−0.123 (−0.950 to 0.705)	1
		<1	1.950 (0.941 to 2.960)	<0.001*	−0.071 (−0.898 to 0.757)	1
		1–5	0.312 (−0.559 to 1.183)	1	−1.252 (−1.924 to −0.580)	0.001*
		<5	0.035 (−0.301 to 0.370)	1	−0.192 (−0.455 to 0.070)	0.442
– BiZact	2	Total	1.979 (0.856 to 3.101)	0.002*	−0.106 (−1.066 to 0.855)	1
		<1	2.027 (0.904 to 3.150)	0.002*	0.006 (−0.959 to 0.971)	1
		1–5μm	0.086 (−0.813 to 0.985)	1	−1.478 (−2.187 to −0.769)	<0.001*
		<5	−0.006 (−0.359 to 0.347)	1	−0.233 (−0.518 to 0.051)	0.319
Operating theatre staff exposure	10					
– Bipolar electrocautery	10	Total	2.250 (1.393 to 3.107)	<0.001*	0.154 (−0.483 to 0.791)	1
		<1	2.057 (1.230 to 2.883)	<0.001*	0.025 (−0.592 to 0.642)	1
		1–5	1.099 (0.304 to 1.895)	0.016*	−0.461 (−1.048 to 0.126)	0.241
		<5	0.162 (−0.132 to 0.456)	0.539	−0.064 (−0.283 to 0.156)	1
– Cold dissection	8	Total	2.180 (1.293 to 3.066)	<0.001*	0.083 (−0.593 to 0.760)	1
		<1	2.006 (1.146 to 2.865)	<0.001*	−0.025 (−0.686 to 0.635)	1
		1–5	0.851 (0.036 to 1.666)	0.082	−0.709 (−1.323 to −0.096)	0.048*
		<5	0.142 (−0.164 to 0.447)	0.710	−0.084 (−0.320 to 0.151)	0.952

*Statistically significant difference. A linear mixed model was used in pairwise comparisons of tonsillectomy techniques to operating theatre background and coughing. Values were transformed using a logarithm to the base 10 for analysis. *P*-values were reported after adjustment for multiple comparisons with Bonferroni correction using correction factor of two in staff exposure comparisons and correction factor of three in surgeon exposure comparisons. No adjustment to confidence interval (CIs) was performed.

bipolar electrocautery and cold dissection were compared. We observed significant differences in the surgeon's exposure between bipolar electrocautery and the other two techniques. Detailed results of the tonsillectomy technique comparisons are presented in Table 3. All three techniques were used in the tonsillectomy procedures of two patients. The total particle concentrations generated during bipolar electrocautery, cold dissection and BiZact use for those two patients are shown in Figure 2. In the manual, observational review, no increase in aerosol concentration was observed in relation to a specific point of the procedure (such as tonsil removal).

Discussion

We report here the first investigation into the risk that tonsillectomy poses in terms of aerosol-particle release, where surgeons and operating theatre staff are exposed to aerosols despite efficient operating theatre ventilation. The highest aerosol concentrations were observed during the use of the bipolar electrocautery technique, resulting in significantly higher exposure when compared with exposures measured during coughing. Nonetheless, careful selection of operational technique can significantly reduce the exposure of surgical staff to aerosols, which is particularly important during early airborne epidemics and pandemics before valid screening tools and vaccinations.

Our results showed that the bipolar electrocautery technique generated significantly greater amounts of particles than other techniques or coughing, especially with small less than 5 μm particles, which have previously been shown to carry most of the pathogens.[24] In contrast, current-carrying electrocautery (BiZact) and cold dissection did not generate aerosol particles more than normal coughing and thus do not pose a greater risk to operating theatre staff than normal patient contact. To rationalise greater personal protective equipment use for only certain medical procedures, this everyday exposure should be surpassed. Our findings are important when planning elective procedures, assessing the exposure risks and planning the use of personal protective equipment during the procedures, especially during the Covid-19 pandemic and other epidemics caused by airborne pathogens, such as influenza.[25]

Our findings regarding aerosol generation when using the cold dissection technique or bipolar electrocautery technique are in line with earlier findings observed in rhinological and otological procedures; when using cold dissection, the generation of small particles has been observed, but it has not been remarkable.[20,21,26] By contrast, the use of the bipolar electrocautery technique has been shown to generate high particle

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Table 3. Comparisons of tonsillectomy techniques from the perspectives of operating surgeons and other operating theatre staff

Parameter	Bipolar electrocautery & cold dissection (mean difference (95% CI))	*P*-value	Bipolar electrocautery & BiZact (mean difference (95% CI))	*P*-value	Cold dissection & BiZact (mean difference (95% CI))	*P*-value
Surgeon exposure						
– Total particles	1.640 (0.858 to 2.422)	<0.001*	1.637 (0.457 to 2.817)	0.003*	−0.003 (−1.281 to 1.275)	1
– <1 µm particles	1.533 (0.727 to 2.338)	<0.001*	1.467 (0.249 to 2.685)	0.012*	−0.066 (−1.383 to 1.252)	1
– 1–5 µm particles	0.011 (−0.280 to 0.303)	1	0.208 (−0.232 to 0.648)	0.771	0.197 (−0.280 to 0.673)	0.966
– >5 µm particles	0.000 (−0.135 to 0.136)	1	0.048 (−0.147 to 0.243)	1	0.047 (−0.171 to 0.265)	1
Operating theatre staff exposure						
– Total particles	0.049 (−0.258 to 0.357)	0.753	–	–	–	–
– <1 µm particles	0.040 (−0.298 to 0.378)	0.816	–	–	–	–
– 1–5 µm particles	0.191 (−0.125 to 0.506)	0.236	–	–	–	–
– >5 µm particles	−0.014 (−0.153 to 0.124)	0.837	–	–	–	–

*Statistically significant difference. Linear mixed model was used in multiple pairwise comparison of all three tonsillectomy techniques measured from surgeon's perspective, and pairwise comparison of bipolar electrocautery and cold dissection techniques measured from the perspective of other operating theatre staff. Values were transformed using a logarithm to the base 10 for analysis. *P*-values and confidence intervals. (CIs) of surgeon exposure reported after Bonferroni correction for multiple comparisons using correction factor of 3

concentrations.[27,28] The aerosol generation while using advanced electrocautery, such as current-carrying electrocautery, has not been studied before in any surgical approach. We were able to measure only two BiZact operations, so our results are preliminary, but they strongly suggest that controlling current during electrocautery significantly reduces aerosol release and thus the risk of airborne infection to the surgeon and other staff.

The operating theatres' ventilation rate was highly efficient; total clearance occurred every 6 to 10 seconds in the area where tonsillectomy was performed. Efficient ventilation in operating theatres quickly reduced aerosol concentrations in the operating theatre air and therefore protects operating theatre personnel from airborne diseases during procedures. Only the surgeon's aerosol exposure with the bipolar electrocautery technique procedures was significantly higher than the aerosol exposures during coughing. Thus, in addition to personal protective equipment, both good ventilation of the premises and the greatest possible distance to the patient seem to play an important role in reducing aerosol exposure.

Earlier studies have concluded that the cold dissection technique is the suggested technique for adult tonsillectomy because of its lower rate of post-operative haemorrhage and pain. For example, the National Prospective Tonsillectomy Audit of England and Northern Ireland has recommended cold dissection technique as a priority technique.[7,29] Still, electrosurgical instruments have remained popular, possibly because of operator-related factors. The rapid procedure time and decreased bleeding during surgery are appreciated by the surgeon.[6] Our results strongly suggest that using the cold dissection technique is also safer for operating theatre staff in the context of airborne diseases. Nevertheless, if the duration of the operation is significantly extended with the cold dissection technique (an assumption not supported by the literature), the risk should be reassessed. Earlier works have demonstrated that coughing combined with a two-hour exposure time may pose a significant risk of virus transmission, and a cough coming straight at a target can predispose an individual to an infection even after short exposure.[30,31] Comparing these findings to our results, it can be assumed that the critical exposure time leading to infection would be even shorter because (1) the aerosols come directly towards the surgeon because of the surgical position of the patient and the surgeon, and (2) the aerosol concentration when using electrocautery exceeds the aerosol production of coughing.

Some limitations in our study warrant discussion. First, we measured the aerosol concentration, not the exact viral load. The risk assessment includes the amount of aerosols, the infection situation, the patient's medical history and status, as well as the exposure time and environmental conditions. A link between viral load and airborne concentration in natural respiratory activities has been previously observed, and it is expected that similar viral load would affect risk for generated aerosols.[32] However, whether the procedure used causes changes to viral infectivity because of temperature or mechanical aspects should be studied separately for different viruses. Second, it is unclear how well the viruses will withstand the heat generated during electrocautery. However, even the severe acute respiratory syndrome coronavirus-2 virus, which is sensitive to environmental factors, has been shown to maintain its infectivity several minutes after heating to 70°C.[33] Thus, it is likely that at least some of the pathogens carried by aerosols would be infectious after electrocautery. Third, as all the measurements were carried out with the same optical particle sizer instrument, the exposure of the surgeon and the staff could not be determined during the same procedure. In the future, simultaneous measurements from different areas of the operating theatre could provide additional information about the risk to staff. Fourth, the use of a collection tube for the surgeon's exposure measurements reduced the collection of bigger (more than 5 µm) particles because these larger particles stayed in the tube and could not be measured. However, most of the released particles during surgery have been found to be small (less than 1 µm) particles,[3] and most pathogens are carried by less than 5 µm particles.[24] Fifth, our results cannot be directly applied to children's tonsillectomies because all our patients were adults. Also, in children's tonsillectomies, the loss of blood during the surgery is often greater, and because of the smaller circulating blood volume, bipolar electrocautery technique has been recommended as a priority technique.[29]

There are no published studies on the transmission of Covid-19 in the operating theatre or, more specifically, in

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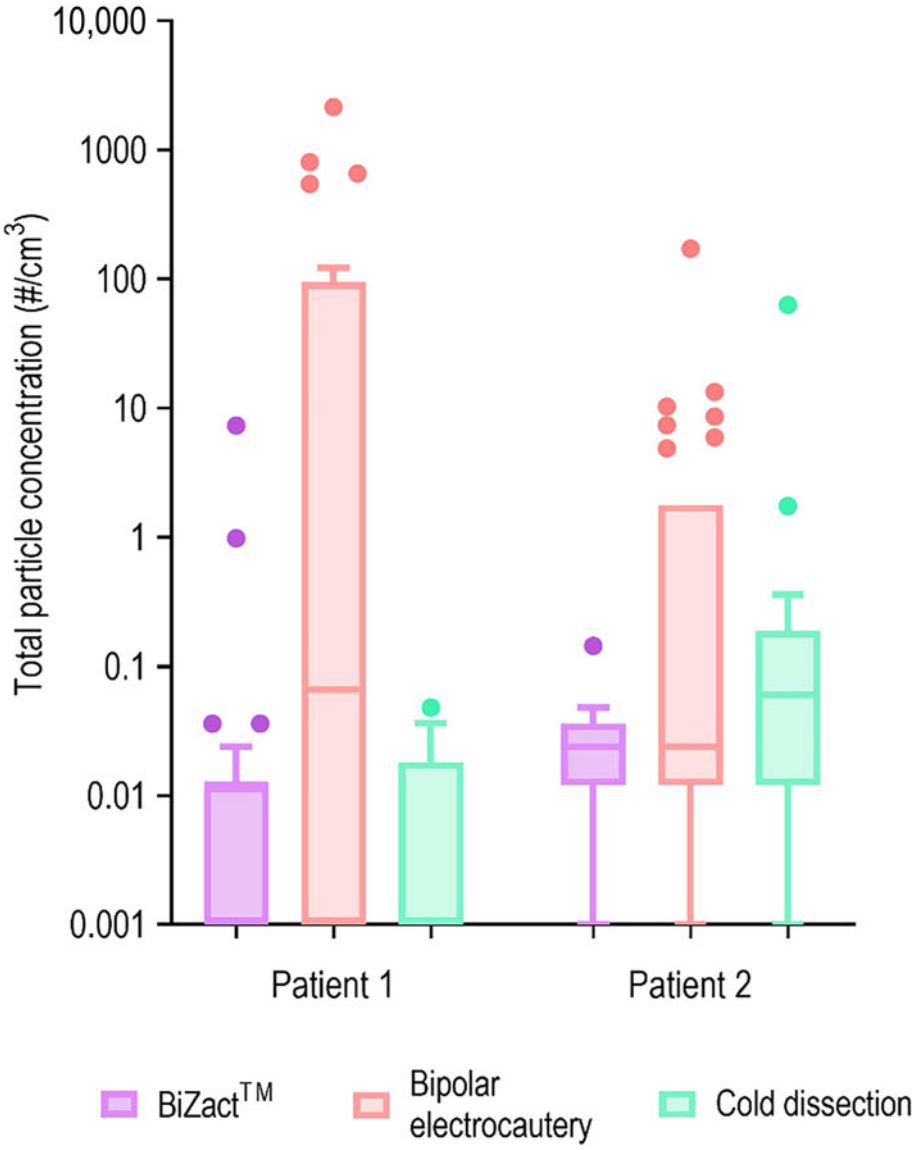

Figure 2. Total particle concentrations of BiZact, bipolar electrocautery and cold dissection on two patients on logarithmic scale. Median (solid line). Interquartile range (box). Values within 1.5 interquartile range of the quartiles (whiskers) with outliers (dots).

the ENT operating theatre. In contrast, several studies have been published on the spread of Covid-19 in hospitals. However, even these do not show infections related to the operating theatre, but rather the chains of infection in the emergency theatre and wards.[34–36] To our knowledge, this is the first study to measure real-life aerosol exposures of operating theatre personnel during tonsillectomy, to compare different surgery techniques and equipment regarding aerosol generation, and to compare the exposure dose of the surgeon and other staff.

As the ideal technique for tonsillectomy is controversial, the knowledge of aerosol generation during tonsillectomy provides valuable information to inform the choice of technique. All the procedures were performed using either one or a combination of the three different techniques and otherwise followed the same operational protocols, including suction, which was used throughout all the tonsillectomies. Thus, the aerosol-reducing role of suction caused no bias in our study.[37] We were also able to compare the aerosol generation during the cold dissection technique, bipolar electrocautery technique and BiZact technique in the same operation because in two operations the surgeon removed the first tonsil with a combination of the cold dissection technique and bipolar electrocautery technique and the second tonsil with BiZact. The possibility to compare techniques in pairs increases reliability of our results as it reduces the bias caused by patient, surgeon and operating theatre dependent factors.

- Viral diseases can spread through aerosols produced by coughing, talking, exhalation and in some surgical procedures
- No quantitative evidence exists regarding the risk posed by many common procedures
- During peaks of disease in a pandemic with airborne potential, a shift to only cold steel tonsillectomy offers the potential for lower aerosol generation
- Lower aerosol generation helps to avoid cancellations or delays in operations because of the fear of aerosols
- This research provides one element for risk assessment and risk minimisation in the operating theatre

Because we measured the particle size and distribution from both the surgeon's and other operating theatre personnel's distances from the patient, our results reflect the differences in the staff exposure to aerosols. All the procedure details were carefully recorded, which allowed us to evaluate aerosol generation during the studied procedures step by step. All the staff wore masks, which has been observed to reduce aerosol release and thus reduce biases caused by staff respiratory behaviour.[38,39] In our material, patients underwent

https://doi.org/10.1017/S0022215123000324 Published online by Cambridge University Press

tonsillectomy for various indications: 11 for chronic tonsillitis, 3 for peritonsillar abscess and 4 for tonsillar hyperplasia. The effect of different indications of tonsillectomy on aerosol generation during the procedure has not been studied, and our small data do not allow reliable analysis between patient groups. For example, inflammation is associated with the fluid accumulation in tissues because of the increase of the permeability of blood vessels.[40,41] An inflammatory condition implies more humidity of tissues, rendering separation of particles less evident than for dry tissues and could thus cause reduced aerosol generation. However, the issue should be investigated in the future, and this should be considered as a potential limiting factor in our research.

Conclusion

Overall, aerosol generation was observed in all 18 tonsillectomies and was found in high concentrations when the bipolar electrocautery technique was used. Our findings support the view that the cold dissection technique could be the primary surgical technique in tonsillectomy, especially during epidemics and pandemic peaks, given its added benefit of likely decreased aerosol exposure. In addition to the previous patient safety considerations, it seems to be the safest option for the surgeon and other operating theatre staff. Similar to the cold dissection technique, current-controlled electrocautery (BiZact) emerged as an equally aerosol-safe alternative in our study. However, because of the small sample size, more research is needed to confirm the findings about the cold dissection technique and BiZact and to evaluate aerosol generation during paediatric procedures.

Acknowledgements. This work was supported by the Helsinki University Hospital Research Fund, Finska Läkaresällskapet (ES) and Jalmari and Rauha Ahokas Foundation (ES).

Competing interests. None declared.

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