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ORIGINAL ARTICLE

Aerosol Production with Surgical Instrumentation: Implications for Head and Neck Surgery in the COVID-19 Era

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Abstract Evaluating the aerosolization of droplets from surgical instruments to assess the implications of surgery in SARS-CoV-2 transmission for both patients and providers. Cadaver study. Outpatient surgery center. Aerosolized particles between 0.3 and 25 microns were measured. Instruments tested included monopolar cautery with and without suction, bipolar cautery, a bipolar vessel sealing device, and tissue scissors. Each trial was compared to a background reading. Monopolar cautery without suction, Ligasure used continuously and Bipolar cautery produced the most aerosols. Monopolar cautery with simultaneous suction produced no detectable aerosols. Ligasure used for a single cycle produced notably fewer aerosols than during continuous use. Most aerosols produced were < 5 microns. These data support n95 use during surgical management of the upper aerodigestive tract, as well as the use of suction in the surgical field.

Keywords COVID-19 · Aerosols · Head and neck cancer

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Introduction

Beginning in December 2019, reports suggested that a novel coronavirus, now named SARS-CoV-2, was circulating in the city of Wuhan, China. Since then, the virus has rapidly circulated around the world leading to a worldwide pandemic. In addition to concern regarding public transmission, healthcare workers carry the additional risk of iatrogenic aerosolization of infectious particles during standard medical treatments. Otolaryngologists, in particular, were found in the Chinese literature [1] to be highly affected by SARS-CoV-2. It was theorized that this was due to a high number of aerosol-generating procedures in their respective practices.

It is known that the novel coronavirus is spread through droplet transmission and early studies suggest that large droplets are the typical transmission vehicle for the virus. However, early work comparing SARS-CoV-1 and SARS-CoV-2 demonstrate that both viruses are stable in smaller aerosols over the period of hours [2]. In addition, SARS-CoV-1 has been found in aerosols as small as 0.2 microns as sampled from ambient air in a patient's room post-extubation [3]. This means that should secretions from an infected person be aerosolized, both the large and small aerosolized particles could provide a pathway for occupational exposure [4].

The goal of this study is to quantify the aerosol production of surgical instrumentation used during open approaches to upper aerodigestive tract mucosa. Each device was evaluated as might be used clinically. These data will be useful in determining safe instrumentation during routine and emergency surgery in the COVD-19 era, and will continue to inform proper PPE utilization for the protection of operating room staff [5, 6]. To our knowledge this is the first cadaveric study investigating aerosol

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production by open instrumentation of the upper aerodigestive tract.

Materials and Methods

Study Design

This study utilized cadaveric tissue and involved no human subjects; thus, no IRB was required per University of Texas Health Science Center protocol. The study was set in an operating theatre (2059 cubic feet) in an outpatient surgery center. A single fresh-frozen cadaveric head, thawed to room temperature, was utilized for this study.

Aerosol Sampling

A laser-diode particle counter (Lasair III 310C, Particle Measuring Systems) was used to measure aerosols from 0.3 microns to 25 microns. Six user-adjustable channels were used to determine counts of particles separated by particulate size. The intake tubing for the study was placed at the nasal tip, and the intake flow rate was set at 28.3 L/min. Readings were taken to measure background particle measurements immediately prior to each experimental measurement being recorded. The intake was first run for 30 s to obtain background measurements, and then three 30 s samplings with the instrument engaged. The number of total and size stratified aerosols generated with each instrument was determined using this technique. The suction was held for 2 s within the tested cavity (oral/oropharynx/nasal cavity) to clear any residual aerosolized particulates from the cavity prior to taking a background reading.

Patient Simulation

The cadaver head was warmed to room temperature and was placed supine on the operating room table. The particle counter was secured to the nasal tip (Fig. 1). Instruments tested included Bipolar cautery (Bayonet bipolar forceps, Medtronic), monopolar cautery with and without suction (Pencil with protected spatula tip, Medtronic), electrosurgical bipolar vessel-sealing device (Ligasure Exact, Medtronic), and cold steel tissue scissors (Metzenbaum dissecting scissors).

The bipolar cautery was used at a setting of 20, applied along the medial wall of the maxillary sinus within the middle meatus. The monopolar cautery was used for three separate readings: on the cut setting of 20 with and without suction, and the coagulation setting of 20 with suction. The monopolar cautery device was used on tissues of the oral cavity and oropharynx including the oral tongue, tongue base, buccal mucosa, and soft palate. The Ligasure device was allowed to complete the full sealing cycle as per the devices protocol at a setting of 3 and was used on the oral tongue. The Metzenbaum dissecting scissors were used on the oral tongue. All devices were used continuously for the 1.5 min particle reading, with one exception. For the Ligasure device, the first test entailed repeating sealing cycles continuously during the reading time. A second test was then performed in which the manufacturer firing cycle was completed only once during each 30 s period. This was done to more closely mimic how the device would be used in the operating room.

Fig. 1 Fresh cadaveric head on operating theatre table

Statistical Analysis

During each sampling period, the particle counter was run continuously. The mean for the three trials was obtained for each device and converted to particles per cubic feet per minute, by doubling the mean calculated value.

The Kruskal–Wallis test was used to obtain mean total aerosols and mean aerosols of each size generated for each instrument. Mann–Whitney tests with Bonferroni correction were used to compare pairs within the instruments.

Results

Generation of aerosols less than 25 microns using a variety of surgical instruments

Three different instruments were tested in the oral cavity including monopolar cautery with and without attached suction (Pencil with protected spatula tip, cut setting at 20, coagulation setting at 20, Medtronic), electrosurgical bipolar vessel-sealing device (Ligasure Exact, setting at 3, used continuously for 30 s and fired for one manufacturer cycle, Medtronic), and non-powered tissue scissors (Metzenbaum dissecting scissors). Bipolar cautery (Bayonet bipolar forceps, at setting of 20, Medtronic) was used in the nasal cavity. The mean total particle counts between 0.3 microns and 25 microns over 3 samplings of aerosols generated over the background aerosol value is shown in Fig. 2. Monopolar cautery without suction, Ligasure used continuously and Bipolar cautery produced the most aerosols. Monopolar cautery with simultaneous suction in the surgical field produced no detectable aerosols. Ligasure used intermittently (mean: 39.5×10^5 Aerosols/ft^3/min; 95% CI: 3.6×10^5–75.4×10^5 Aerosols/ft^3/min) produced notably fewer aerosols than Ligasure used continuously. Use of non-powered tissue scissors (mean: 1.7×10^5 Aerosols/ft^3/min; 95% CI: 1.07×10^5–2.35×10^5 Aerosols/ft^3/min) produced minimal aerosols compared to other aerosol generating instruments tested.

Size distribution of the aerosols generated from aerosol generating instruments.

Four instruments found to generate aerosols over background levels were analyzed for distribution of particle size shown in Fig. 3**.** In this evaluation, monopolar cautery without suction and Ligasure used continuously produced the most particles greater than 1 micron in size. The remaining aerosol generating instruments produced more aerosols less than 1 micron than aerosols 1 micron or greater. No significant quantity of aerosols 10 microns or greater were detected from any instrument (Table 1).

Discussion

In this study, we found a heterogeneous picture of aerosol sizes created during use of surgical instruments typically employed in open surgery of the mucosal surfaces of the head and neck. We tested commonly used instruments at our institution in head and neck and endocrine surgery: monopolar cautery, bipolar cautery, the Ligasure bipolar vessel sealing device, and cold dissecting instruments. Importantly, we tested each instrument as it would be used clinically, to produce the most accurate model of aerosol production possible. Our data show that powered instrumentation of all types produces some amount of aerosolized particles in a variety of sizes. However, similar to published literature, we found that these instruments generated particle sizes typically less than 10 microns [4]. The sizes of particles produced inform our ability to develop protective measures for surgeons and operating room staff.

Previously published literature from our institution looked primarily at rhinologic instrumentation given global concerns in the skull base surgery community regarding SARS-CoV-2 exposure [4, 7]. Our study is the first of its kind to produce experimental data of aerosol generating procedures (AGP's) in a cadaveric head with the instruments commonly used in mucosal surgery of the head and neck. We utilized the monopolar cautery on tonsil and tonsillar pillar tissue, as would be commonly used during a

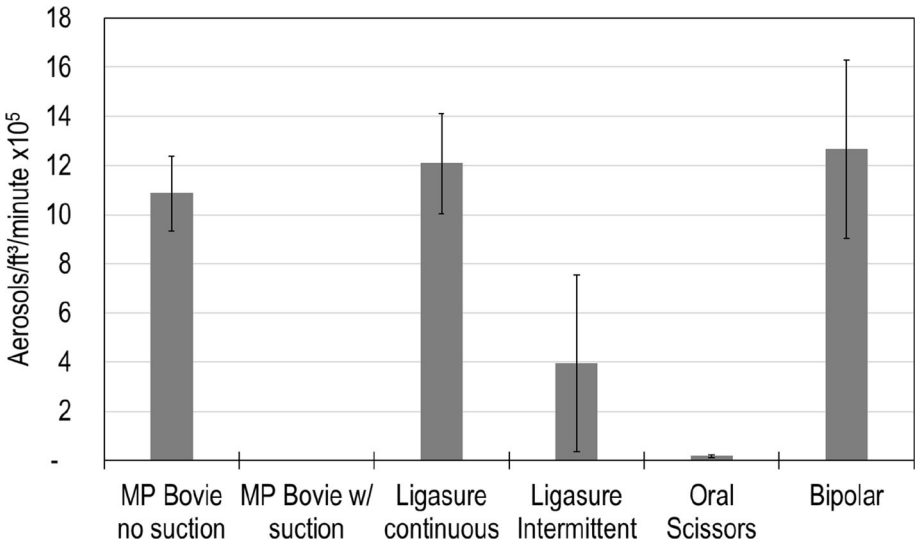

Fig. 2 Aerosols generated from common head and neck surgery instruments. Mean total particle counts per cubic feet over the background reading with error bars representing the 95% confidence interval. Monopolar (MP) bovie with and without suction, Ligasure continuously and intermittently used, and oral scissors were tested in the oral cavity. Bipolar was tested in the nasal cavity

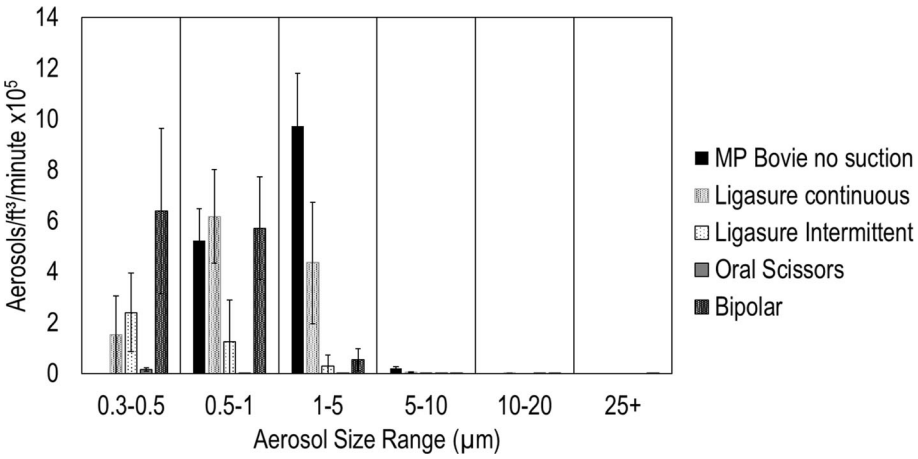

Fig. 3 Size distribution by micron of generated aerosols by aerosol generating instruments per cubic feet over the background reading with error bars representing the 95% confidence interval

Table 1 Size distribution of aerosols generated per cubic feet over background reading

Net particle Counts by μm size Δ (95% CI)							
description	Sample Time, (s)	0.3–0.5	0.5–1	1–5	5–10	10–20	25 +
MP Bovie no suction	60	−427,190 (−634,505, −219,875)	522,093 (394,652, 649,533)	972,757 (764,373, 1,181,142)	18,969 (10,259, 27,679)	15 (9, 20)	2 (0, 4)
MP Bovie w/ suction	60	−65,655 (−87,041, −44,269)	−8,215 (−10,302, −6,129)	−311 (−499, −122)	7 (−12, 25)	−13 (−17, −8)	−1 (−3, 1)
Ligasure continuous	60	151,867 (−1,567, 305,301)	617,437 (432,503, 802,371)	435,022 (195,859, 674,185)	4,219 (2,016, 6,422)	364 (24, 704)	0 (−2, 2)
Ligasure Intermittent	60	240,487 (85,844, 395,129)	125,112 (−38,783, 289,007)	29,439 (−14,090, 72,968)	71 (−39, 182)	4 (−9, 1)	0 (−2, 2)
Oral Scissors	60	16,319 (9,691, 22,948)	376 (104, 648)	434 (251, 617)	6 (−2, 14)	3 (−5, 11)	0 (−3, 2)
Bipolar	60	639,824 (314,810, 964,838)	571,779 (369,295, 774,263)	54,703 (11,293, 98,114)	21 (9, 32)	7 (1, 13)	1 (0, 2)

routine tonsillectomy. The Ligasure was tested on oral tongue, floor of mouth, and buccal mucosa, as it would be commonly used in resection of a mucosal lesion of the oral cavity. The Ligasure has a cycle time that is limited by the impedance of tissues ligated. In practice, the Ligasure remains active in providing bipolar energy to the tissue until it is fully cauterized. This means that the Ligasure can be used to seal a discrete amount of tissue for a single cycle, or alternatively, it can be fired in succession to resect a large amount of soft tissue, as would be required during resection of an oral cavity mass. This results in a vastly different time course for the AGP, and for exposure to the surgeon. The Ligasure was thus tested using these two different techniques in our study, described as one cycle versus continuously, to mimic the aerosol production during these two different use techniques. We believe that the techniques used, as well as the utilization of a fresh cadaver head, have allowed our study to produce data most representative of real-world use.

The size of an aerosol particle in the literature can vary widely, but has been discussed generally as < 100 microns in diameter [8]. Importantly, the definitions that govern types of spread in the context of infectious disease (eg airborne versus droplet precautions) are a parallel and overlapping definition to aerosols. Pathogens that spread by airborne transmission are found in particles < 5 microns, while droplet transmission occurs in particles strictly 5–25 microns [5]. As they are physically larger, droplets are subject to gravity when expelled into the air (such as sputum expectorated with a cough). These heavier particles settle much faster and typically do not spread far from the source. Because of their smaller inertia, pathogens that can be transmitted through particles < 5 microns require more rigorous protective equipment and precautions, including negative pressure rooms and n95 masks [9].

The size of aerosol particles produced during AGPs are typically reported between 8 and 500 microns [10, 11]. However, our data show that a significant number of smaller aerosols (< 5 microns) are produced during use of monopolar cautery, bipoloar cautery, and Ligasure on cadaveric oral mucosa tissue. During the SARS epidemic in 2002–2003, SARS-CoV-1 DNA could be found in air samples from the rooms of SARS patients, 8 h after an intubation/extubation event, suggesting that coronaviridae can be transmitted in lighter, smaller aerosols [9]. Additionally, data from early in the COVID-19 pandemic showed that SARS-CoV-1 and SARS-CoV-2 have similar transmission dynamics [2]. These data support the use of higher filtration systems in protecting against SARS-CoV-2 transmission.

Proper PPE protocol can be informed with data from this cadaveric study. The standard surgical mask cannot protect the surgeon adequately against transmission of smaller aerosols in the < 5 micron range [12]. Aerosols in this range made up the majority of particulates produced in this study. These simultaneously are the aerosols that are able to suspend in air and travel to the deepest parts of the alveolar lung tissue [13]. The type II pneumocytes in this location of the lung express the SARS-CoV-2 spike protein receptor at a high rate, making this an important pathway for infection. N95 masks, currently recommended as standard PPE for protection from SARS-CoV-2 infection, can filter particulates > 0.4 microns a 99.97%, and 0.3 micron particles at 95% (NIOSH) [14, 15]. The particle dynamics of aerosols of 0.3 microns in size make them the most difficult to filter and NIOSH ratings note that particles both larger and smaller than 0.3 microns are filtered at a higher rate than those of exactly 0.3 microns [16, 17]. The data produced from our study continue to support the use of n95 masks during surgery of the mucosa of the oropharynx as a preventative measure against SARS-CoV-2 transmission from patient to operating room staff. This is particularly important during AGPs including the use of cautery on the mucosa of the upper aerodigestive tract.

Lessons can also be taken from prior data looking at the evacuation of surgical smoke from the operative field. Bruske-Hohlfeld et al. recorded the size of smoke particulates from cautery, laser, and ultrasonic powered instrumentation to be 0.07, 0.31, and 0.35 to 6.5 microns, respectively [18]. Smoke evacuators have been used to reduce exposure to surgical smoke for many years across various surgical fields. These evacuators have been attached to the surgical instrument or placed adjacent to the surgical field and have been successful in reducing smoke in both open and endoscopic procedures. In previous studies, these smoke evacuators display good success in significantly reducing the quantity of aerosols expelled from the surgical field in the 0.2–25 micron range, the same as was tested in our study [12, 19–21]. Previous data published by our institution also show an significant reduction of aerosols generated from the field during simultaneous application of suction during instrumentation of the nasal cavity [4]. In our study, simultaneously applied suction results in a significant reduction in aerosols of all sizes generated from the surgical field. In our data, for example, monopolar cautery produced on average 522,093 aerosol particles of sizes 0.5–1 microns over 60 s. After applying suction to the field, the number of aerosols produced over the same time frame was zero. These data provide a numerical example of how continuous application of suction can significantly reduce potential aerosol exposure to the surgeon and OR staff.

Our study has several limitations, some of which are related to our current knowledge base regarding SARS-CoV-2. Minimal infectious dose for contracting COVID-19 has not been determined as of writing of this manuscript [22]. These data, once elucidated, will significantly inform our modeling of risk during AGPs. Our model takes place in an operating theatre with a fresh cadaver head. This provides an accurate representation of a patient presentation, but the particle dynamics of airflow in this specific operating room with this particular patient anatomy may cause values to vary to an unknown degree. Variations in a particular operating theatre's air flow and filtration also will possibly alter the spread and dispersion of aerosols. This study could be repeated in the future in different settings, with different patients, including cadaveric and live human subjects, to provide more robust data. In particular, while this study demonstrates value to applying suction to the surgical field, our data are insufficient to recommend against the use of n95 masks in this setting. Further experimental data may evaluate and validate the safety this PPE use pattern.

Conclusion

In conclusion, our study provides data on aerosols produced by commonly used surgical instruments in head and neck surgery. We demonstrate that powered instrumentation produces small aerosols, of a size that could carry SARS-CoV-2 virus, and that the quantity of aerosols expelled from the surgical field is significantly reduced by the application of suction to the field. Our data support the continued use of n95 masks during use of cautery on the mucosa of the upper aerodigestive tract to reduce transmission of SARS-CoV-2. To our knowledge, this is the first study to evaluate AGPs using powered instrumentation on the oral mucosa of an intact cadaveric head. This provides the most accurate picture to date of the aerosol production

during open surgery of the upper aerodigestive tract mucosa.

Author Contribution Garren Low: Study protocol design, statistical analysis, literature review, manuscript writing, editing. Bailey LeConte: study data collection, statistical analysis, literature review, manuscript writing. Arturo Eguia: statistical analysis, figure & table production, manuscript writing. Ashley Kim: literature review, statistical analysis, figure & table production. Ron Karni: manuscript writing, editing. Amber Luong: study protocol design, literature review, manuscript writing, editing. Kunal Jain: literature review, manuscript writing, editing.

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Availability of Data and Material Complete data available at request.

Declarations

Conflict of interest RK serves as a consultant for and receives speaking fees from Medronic (Dublin, Ireland), and serves as a consultant for and serves on the Scientific Advisory Board for Tactile Medical (Minneapolis, MN). AL serves as a consultant for Inquis Medical (Atherton, CA), Medtronic (Jacksonville, FL), Aerin Medical (Austin, TX), Sanofi (Paris, France) and Stryker (Kalamazoo, MI). She is on the scientific advisory board for ENTvantage (Austin, TX) and has served on advisory boards for Novartis (San Francisco, CA) and Sanofi (Paris, France).

Ethics Approval No IRB approval was required after discussion with University of Texas Health Sciences Center at Houston IRB.

Consent to Participate No live human subjects.

Consent to Publish No live human subjects.

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