Endonasal Instrumentation and Aerosolization Risk in the Era of COVID-19: Simulation, Literature Review, and Proposed Mitigation Strategies

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Short title: Endonasal Aerosolization Risk in the COVID-19 Era

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Abstract

Introduction: International experience with COVID-19 suggests it poses a significant risk of infectious transmission to skull base surgeons, due to high nasal viral titers and the unknown potential for aerosol generation during endonasal instrumentation. The purpose of this study was to simulate aerosolization events over a range of endoscopic procedures to gain an evidence-based aerosol risk assessment.

Methods: Aerosolization was simulated in a cadaver using fluorescein solution (0.2mg/10ml) and quantified using a blue-light filter and digital image processing. Outpatient sneezing during endoscopy was simulated using an intranasal atomizer in the presence or absence of intact and modified surgical mask barriers. Surgical aerosolization was simulated during non-

powered instrumentation, suction microdebrider, and high-speed drilling following nasal fluorescein application.

Results: Among the outpatient conditions, a simulated sneeze event generated maximal aerosol distribution at 30cm extending to 66cm. Both an intact surgical mask and a modified VENT mask (which enables endoscopy) eliminated all detectable aerosol spread. Among the surgical conditions, cold instrumentation and microdebrider use did not generate detectable aerosols. Conversely, use of a high-speed drill produced significant aerosol contamination in all tested conditions.

Conclusion: We confirm that aerosolization presents a risk to the endonasal skull base surgeon. In the outpatient setting, use of a barrier significantly reduces aerosol spread. Cold surgical instrumentation and microdebrider use pose significantly less aerosolization risk than a high-speed drill. Procedures requiring drill use should carry a special designation as an “Aerosol Generating Surgery” to convey this unique risk, and support the need for protective PPE.

Introduction

The disease COVID-19 resulting from the novel coronavirus strain (SARS-CoV-2) represents an extraordinary threat to the health of the global population. Since its emergence in Wuhan, China in December 2019 it has rapidly spread throughout the world following an exponential growth curve prompting it to be classified as a pandemic by the World Health Organization (WHO) on March 11, 2020. In addition to the accelerating death toll among patients, evolving information regarding infection transmission among healthcare workers (HCWs) has raised concerns within the medical workforce regarding best practices for personal protective equipment (PPE) use in a resource and information constrained environment. Anecdotal international reports regarding high rates of infection specifically among Otolaryngologists [1] have raised further critical questions with respect to the safety of performing both outpatient endoscopy as well as sinus and skull base surgery in patients with unknown COVID-19 status (UCS).

These concerns arise out of a high degree of uncertainty as to whether 1) certain endonasal procedures can generate aerosols and 2) whether COVID-19 can behave as an opportunistic airborne pathogen and transmit infection via these potential aerosols. These questions have become

even more salient as data regarding elevated nasal/nasopharyngeal viral loads of even asymptomatic patients [2] and prolonged viral persistence in air [3] have emerged.

Concepts such as nasal aerosolization and the intricacies of PPE policy have remained largely foreign to the modern Otolaryngologic workforce who, as a field, have not found themselves on the frontlines of emerging infectious disease. Unfortunately, with the advent of COVID-19, that era has come to an abrupt end. We must now apply our scientific principles to generate a rational strategy towards the treatment of patients with UCS while simultaneously protecting the healthcare team. The purpose of this study was to therefore simulate nasal aerosolization during a variety of endonasal procedures and propose potential mitigation strategies which are consistent with the evolving literature.

Materials and Methods

Supplies and Equipment

All experiments in the study were performed in a dedicated surgical laboratory on a fresh-frozen cadaver head specimen. The head was prepared by performing a bicoronal craniotomy to enable passage of the atomizer through a small perforation in the posterior cribriform plate. A high definition endoscopic camera with image capture was attached to a 4mm 0° endoscope. A blue light filter (Karl Storz, Tuttlingen, Germany) was used to visualize the fluorescein labeled aerosols with the light setting at 50%.

The fluorescein solution was created using 50ml of sterile water mixed with 1mg of FUL-GLO Fluorescein Sodium (Akorn, Inc, Lake Forest, IL, USA). One ml of this solution was drawn up into a 5cc syringe that was then attached to a MADgic laryngo-tracheal mucosal atomization device (Teleflex Medical, Morrisville, NC, USA) that produces particles between 30 and 100μm in size [4].

Experimental Setup

The cadaver head was placed at the distal edge of a water impervious black mat, forming the apex of a triangle extending to the edges of the mat at a 50-degree angle, with the two sides of the triangle extending from the head measuring 55cm to the edge of the mat. Subdivisions of the mat were made (Figure 1A) with the central portion of the first subdivision positioned 6cm away from the nasal aperture and each subsequent subdivision at 12 cm intervals. Areas of the mat closer to the nare were divided into smaller subdivisions. Each subdivision was at least 10cm in maximum diameter. The distal end of the 0° endoscope was modified with a stack of 3 opaque 10cm-diameter plastic bowls with the endoscope affixed centrally to create a light occlusion device which ensured standardized image capture at a fixed height and angle (Figure 1B).

Experimental Conditions

To simulate outpatient nasal endoscopy, the head was placed in an upright position. The mucosal atomizer was passed through the cribriform plate with the tip positioned posterior to the left internal valve. For each condition, 1ml of the fluorescein solution was atomized by manually plunging the syringe at maximal pressure. The conditions tested included 1) No mask (Figure 1A), 2) Surgical mask (Figure 1C), 3) Surgical mask with perforation intended to allow the passage of an endoscope, and 4) Modified valved endoscopy of the nose and throat (VENT) mask.

The VENT mask was designed to allow modification of a standard surgical mask using low cost and commonly available materials to enable the passage of an endoscope through the mask while maintaining a tight seal to prevent aerosol leakage. The finger of a non-latex glove was cut off while extending the cut 1cm into the palm. The sides of the finger were cut leaving the tip intact. The cut finger was draped over the internal and external sides of a standard surgical mask. Four staples were placed through both sides of the glove and

intervening mask material taking care to create a square with the crown (e.g. long edge) of the staple on the patient side of the mask. After trimming the excess glove material, a slit was then cut through all three layers to enable the passage of an endoscope (Figure 2).

To simulate the surgical conditions, the head was placed in a supine position. For each condition, 2.5ml of the fluorescein solution was used to generously coat the surface of the nasal cavity using the atomizer. The surgical conditions included 1) Nasal endoscopy, 2) Nasal suctioning using an 8 French Frazier suction, 3) Cold, non-powered instrumentation using a endoscopic through-biter, 4 and 5) Cold powered suction microdebridement (4mm Quadcut® blade at 5000 oscillations/min, Medtronic, Jacksonville, Fl) of the posterior and anterior nasal septum; respectively (Figure 1E), 6) External activation the soiled microdebrider, 7 and 8) Cold, powered high speed drilling (Midas Rex Legend Stylus® with 5mm cutting bur at 70,000rpm, Medtronic) of the sphenoid rostrum and nasal beak; respectively (Figure 1F), and 9) External activation of the soiled drill.

Image Processing and Quantification

Images were exported from the endoscopic tower LCD monitor (Karl Storz) and uploaded in JPG format. ImageJ (version 2.0.0-rc-69/1.52p) was used for all image manipulation and measurement. Endoscopic images were loaded into ImageJ and first subject to a binary review of presence or absence of fluorescent aerosolized droplet contamination. This unblinded review was verified by two separate authors (ADW and BSB). Those that were positive were then subject to the following processing algorithm. First, images were cropped to include only the endoscopic field of view. The background was then subtracted algorithmically using a rolling ball radius of 10 pixels, with separated colors and the sliding paraboloid method, to remove background reflected light. Maximum intensity was calculated at this time for nasal endoscopy and surgical drilling conditions. Following this, image brightness and contrast adjustment were set at a minimum of 20 and maximum of 150 for

pixel intensity. Maximum particle size was then obtained by identifying the largest distinct singular droplet on the image followed by a measured diameter, in pixels. Average fluorescence intensity of the entire image was calculated, and background fluorescence from a matched control condition was subtracted from the average image intensity to obtain the final result [5].

Statistical Analysis

Stata version 13 (StataCorp, College Station, TX), software was used for statistical analysis to assess significant differences between droplet size and average fluorescence intensity among groups. GraphPad Prism version 8.0.2 (GraphPad Software, La Jolla, CA, USA) was used for visualization of data. Each condition was performed in technical duplicate.

Results

Simulation of Diagnostic Endoscopy

Among the simulated outpatient conditions, the surgical mask was successful in preventing any detectable aerosol-derived contamination following activation of the atomizer. The no mask condition demonstrated gross aerosol droplet contamination up to 66cm from the nare. The average optical density peaked around 30cm and the maximum droplet size decreased in a stepwise fashion as distance increased (Figure 3). The perforated mask condition also demonstrated gross aerosol transmission (Figure 3 & 4) with a similar droplet size distribution although the total distance was blunted to 42cm from the nare. Within the VENT mask condition, no droplets were detected. This was a significant change from both the unmasked and perforated mask conditions at several distance points ($p<0.05$, two-tailed t-test).

Simulation of Endoscopic Endonasal Surgery Using Non-powered Cold Instrumentation

The cadaver head was placed in the surgical supine position with the nostril aperture at the edge of the mat for all surgical conditions. After coating the nasal cavity with the fluorescein

solution, three separate cold, non-powered experimental conditions including posterior nasal endoscopy with a 0° endoscope, nasal suctioning with an 8 French Frazier suction, and endoscopic through biting of the middle turbinate were performed. No fluorescein-stained droplets were observed in any of the 19 distribution regions among any condition (Figure 4).

Simulation of Endoscopic Endonasal Surgery Using Powered Suction Microdebrider

With the cadaver head in the surgical position, three experiments were performed using the powered suction microdebrider after coating the nasal cavity with the fluorescein solution. The cutting edge of the microdebrider was open upon introduction and removal of the microdebrider. The microdebrider was applied to the posterior septum with debridement of tissue, anterior septum with debridement of tissue, and finally activated external to the nare after tissue soilage, each for 10s. No fluorescein-stained droplets were observed in any of the 19 distribution regions among any condition (Figure 4).

Simulation of Endoscopic Endonasal Surgery Using High Speed Drill

With the cadaver head in the surgical position, three experiments were performed using the powered high-speed drill at 70,000rpm with a 5mm cutting bur after coating the nasal cavity with the fluorescein solution. The drill was used to remove bone at the sphenoid rostrum, nasal beak, and finally activated external to the nare after tissue soilage, each for 10s. In all conditions, fluorescein-labeled droplets were observed in multiple distribution regions between 6 and 30cm away from the nare (Figure 4). Maximum fluorescence intensity was significantly different in affected areas in drilling conditions compared to baseline ($p<0.01$, two-tailed t-test). External drilling had significantly more distribution regions affected than non-drill surgical conditions ($p<0.05$, Fisher's Exact Test).

Discussion

On December 30, 2019, bronchoalveolar lavage samples of a patient in Wuhan, China with idiopathic pneumonia were positive for pan-Betacoronavirus. Bioinformatic analysis demonstrated that it had a 96% similarity to the bat SARS-like coronavirus strain BatCov RaTG13. This novel zoonotic virus was named SARS-CoV-2 and the resultant disease, COVID-19, has rapidly progressed into a global pandemic [6]. The transmission characteristics of COVID-19 are not fully characterized and thus evidence-based protocols regarding HCW protection have been extrapolated from prior experience with the SARS-CoV and Influenza A/H1N1outbreaks in 2003 and 2009; respectively. Coronaviruses are approximately 0.125 microns in size and are frequently carried in respiratory droplets [7]. One of the critical questions remains as to the risk of aerosolization and airborne transmission of SARS-CoV-2 during both routine clinical care as well as during aerosol generating procedures (AGPs). This risk is particularly germane to Otolaryngologists given of the high viral loads within the nose and nasopharynx [2], the need to perform range of endonasal procedures on both outpatient and surgical patients with UCS, and the dose-response relationship between exposure and infection severity [8]. While patient care must proceed with an abundance of caution, a deeper understanding of the aerosolization risks is needed to guide both near and long-term protection strategies.

Aerosols are produced when air flows across the surface of liquid film, generating small particles at the air-liquid interface. Aerosol particle size is inversely related to air speed and thus an AGP is any procedure capable of generating increased air velocities within the airway. Aerosol formation during AGPs may be divided into patient induced (e.g. irritative procedures that trigger cough or sneeze) or mechanically induced (e.g. intubation, cardiopulmonary resuscitation, bronchoscopy, bag valve mask, non-invasive ventilation, CPAP, BiPAP, and high frequency oscillatory ventilation) [9]. The physiology of patient induced aerosol generation has been studied in depth. Johnson et al found that aerosol

generation typically occurred through fluid film rupture in the distal respiratory bronchioles in the early stages of inhalation. The resulting aerosol was then drawn into the alveoli prior to exhalation [10]. This study also noted that, somewhat counterintuitively, normal breathing can produce higher aerosol concentrations than coughing despite its higher flow rate possibly due to a lower recruitment of contracted bronchioles. Stalhofen et al confirmed these findings noting that aerosols were found beyond the conducting airways and decreased following breath holding suggesting that the opening of closed peripheral airways may be a possible mechanism of particle generation [11]. Furthermore, the particle sizes generated during sneezing or coughing (e.g. “infectious sprays”) have been documented as ranging from <1 to <500μm with greater than 99% of particles larger than 8μm [12] [13].

Regardless of the mode of production, particle size is one of the most important features of aerosols as this directly influences the potential modes of transmission. Airborne transmission is defined as resulting from the inhalation of small particles, often termed droplet nuclei, generally having diameters of 5μm or less. Conversely, droplet transmission is considered a type of direct contact involving larger aerosols up to 100μm which travel less than 1m. Settling velocity due to gravitational acceleration is proportional to the square of the particle diameter and thus larger particles will tend to settle faster and closer to the source as seen in our data [14]. Of note, medium size droplets around 20μm do have the potential to desiccate to form droplet nuclei suggesting that discrete size cutoffs should be interpreted with caution [9]. Airborne pathogens remain infectious over long distances (e.g. >1m) and require both special air handling and PPE. Their transmission may be subclassified as obligate (e.g. transmitted exclusively through droplet nuclei and deposited in the distal lung such as *Mycobacterium tuberculosis*) and preferential (e.g. transmitted by droplets deposited in the airways but also by other routes such as measles). A special class of “opportunistic” airborne pathogens are those which typically transmit through other routes but can become airborne during favorable conditions such as AGPs [15]. For example, the best evidence

from studies of SARS-CoV indicated a consistent association between pathogen transmission and tracheal intubation [16]. Lower quality studies have demonstrated increased risk of SARS-CoV infection associated with tracheotomy, non-invasive ventilation, and manual ventilation before intubation [15].

The small particle size and extended travel of airborne aerosols mandate the use of specific PPE to protect against inhaled transmission. N95 respirators are air purifying respirators which protect against droplet or airborne transmission. They fulfill the filtering efficiency criteria set forth by the National Institute for Occupational Safety and Health (NIOSH) N95 standard which filter with 95% efficiency large droplets and penetrating aerosols 0.3μm in diameter. The European Standard (EN 149:2001) classifies filtering facepiece respirators (FFRs) into three classes, FFP1, 2, and 3 with corresponding filtration efficiencies of 80%, 94%, and 99%. Within this classification, an FFP2 is approximately equivalent to an N95 [17]. Conflicting recommendations may be found between the World Health Organization (WHO) recommendations for mask use in low risk situations and respirators in high risk situations and the Centers for Disease Control (CDC) recommendations for N95 use in both low and high risk situations [18][19][20]. With regard to routine clinical care exclusive of AGPs, there is remarkably little evidence to demonstrate superiority of N95 mask use over standard surgical masks [15]. A recent meta-analysis showed no statistically significant differences in preventing laboratory confirmed influenza, respiratory infection, and influenza-like illnesses using N95 respirators and surgical masks. The authors postulate that these results may be due to lack of compliance both with respect to proper fit as well as maintaining prolonged use given the discomfort associated with it [19].

In light of the conflicting WHO and CDC PPE guidelines coupled with the lack of definitive evidence regarding the efficacy of routine N95 use, it is useful to examine the evidence for and against whether COVID-19 or related viruses may act as an airborne pathogens

following patient and mechanically induced AGPs. SARS-CoV has been established by the Healthcare Infection Control Practices Advisory Committee (HICPAC) as being transmitted through the droplet route however specific AGPs were associated with outbreaks among healthcare workers. Furthermore, SARS-CoV has been measured in air samples within 1m of an infected patient in 11 samples over 8 hours suggesting a high risk for airborne transmission [21]. This data appears to be supported by a recent study demonstrating that aerosolized particles of SARS-CoV-2 less than 5μm remain viable in air for at least three hours [3]. These general findings are best summarized in a systematic review by Tran et al [16] which found that the most consistent statistically significant increased AGP related risk of SARS-CoV transmission to HCWs was tracheal intubation with increased risks also reported in non-invasive ventilation, tracheotomy, and manual ventilation.

Despite these findings, there remains a question as to the magnitude of risk of airborne transmission even during AGPs. Seven case-control studies by the WHO demonstrated that hand hygiene and droplet/contact precautions were sufficient to control SARS-CoV without requiring airborne infection isolation [15] and no experimental studies have demonstrated the transmission of SARS-CoV by airborne aerosol [14]. Thompson et al studied Influenza A H1N1 RNA in aerosols in the vicinity of H1N1 positive patients undergoing AGPs and found no statistically significant increase in the risk of sampling an H1N1 positive aerosol. However, there was a trend towards increased detection rates above background when performing bronchoscopy and respiratory/airway suctioning [13]. In contrast to the intubation risks, the Tran et al study [16] found no significant difference between exposed and unexposed HCWs during all other procedures including insertion of nasogastric tube, suction prior to intubation, collection of sputum sample, and suctioning of body fluids, among others. Furthermore, recent epidemiologic reports from China indicate that despite the fact that 78-85% of human-to-human transmission occurred in family clusters, the within-home attack rates ranged only between 3-10% suggesting a lack of extensive airborne contamination

during cough and sneeze events. Similarly, COVID-19 infection rates among HCWs both in China and the US have largely been thought to originate in the household further suggesting that AGPs within the hospital do not appear to cause widespread airborne associated transmission [6][22]. Even the widely reported van Doremalen [3] study on SARS-CoV-2 viability in air required the use of a three-jet Collison nebulizer fed into a Goldberg drum, conditions which likely do not reflect those of common AGPs [3]. In accordance with these issues, the most recent WHO guidelines report that COVID-19 is primarily transmitted between people through respiratory droplets and contact routes citing an analysis of 75,465 COVID-19 cases in China where airborne transmission was not reported [23][24]. However, the WHO continued to recommend airborne precautions during AGPs. These recommendations are consistent with the European Society of Intensive Care Medicine and Society of Critical Care Medicine [25] and those currently used in Australia, Canada, and United Kingdom [26][27][28]. Of note, these recommendations do conflict with CDC and the European Centre for Disease Prevention and Control who recommend airborne precautions during care of all COVID-19 patients but consider medical masks as an acceptable option in case of shortages [29][30].

The best current evidence suggests that COVID-19 remains, at most, an opportunistic airborne pathogen and that intubation is the best supported AGP for potential HCW transmission. However, this data fails to address the specific risks and procedures which relate to Otolaryngology as a whole and endonasal instrumentation in particular. Reports from Wuhan have suggested that otolaryngologists have been infected at higher rates than other physicians within the same hospital systems [1]. Additionally, an anecdotal report from China indicated that an endoscopic pituitary surgical case prior to the implementation of PPE caused 14 staff members to become infected with COVID-19. The high viral loads of SARS-CoV-2 reported from swabs of the “mid-turbinate” and nasopharynx in both asymptomatic, symptomatic [2], and acute anosmic [31] patients suggest potential explanations for these

high infection rates which must be differentiated into outpatient and surgical exposure events.

From the outpatient perspective, nasal endoscopy alone may be considered at most a potential irritative AGP capable of producing aerosols as a result of sneezing or coughing. This is consistent with the fact that the procedure itself does not produce high air velocities and that nasogastric tube placement has not been associated with HCW transmission [16]. Our data confirm that a simulated sneezing event can generate aerosols which settle maximally between 30cm from the nare but can extend up to 66cm. Spread of these aerosols were effectively prevented by both the intact and VENT mask conditions suggesting that outpatient endoscopy could be more safely performed while using a barrier technique similar to those reported with procedural oxygen masks (POMs) [32].

Aerosol production during endonasal surgery represents a unique condition which fundamentally differs from all other previously discussed AGPs as it occurs in the setting of an occluded lower airway. Consequently, the generation risk, particle size, and transmission distance are entirely a function of the instrumentation utilized. These may be divided into thermal and cold procedures, the latter of which may be further divided into powered and non-powered. Several studies have previously examined aerosol generation during thermal events. Electrocautery has been shown to generate smoke with a mean particle size of 0.07μm whereas laser tissue coagulation creates larger particles (0.31μm). The largest particles produced are associated with an ultrasonic scalpel (.35-6.5micM) [4]. These particles have further been shown to contain detectable viral genetic material although their infectivity remains possible but unclear. For example, Kwak et al utilized a high efficiency collector to obtain surgical smoke in the form of hydrosol and detected hepatitis B virus in 10 of 11 laparoscopic surgeries by PCR [33]. Similarly, Human Papilloma Virus DNA has been shown to be present in laser plumes after CO2 vaporization [34].

As with outpatient endoscopy, cold non-powered endonasal procedures do not exhibit any features of AGPs and our data confirmed that these techniques appear to confer a lower risk of aerosol generation. Conversely, the use of powered instrumentation does have the potential to create high airflow velocities and are therefore of particular concern. The orthopedic literature provides several examples of the risk of operating room contamination using high speed drills. Makovicka et al simulated total knee arthroplasty contaminated with a 5μm fluorescent powder and demonstrated gross spread of particulate matter within the nostrils, eyelashes, and eyebrows of the surgeons wearing standard masks and eyewear [35]. Nogler et al found widespread contamination of live *Staphylococcus aureus* using an ultrasound aspirator and high speed cutting drills in two separate studies [36][37]. Similarly, viable HIV-1 was detected in aerosols generated by power tools including a 30,000rpm spinning router tip [17][38]. These findings are consistent with our data which documented droplet contamination with both endonasal and external activation of the drill head. This risk could even be amplified in a live patient with active bleeding. Interestingly, we failed to identify aerosol contamination in any condition when using the microdebrider. We hypothesize that this may be due to the combination of the relatively low oscillation speeds and the continuous local suction.

There are several limitations to this study which bear frank discussion. The first is that our simulation of irritative sneezing utilized an atomizer which produces sprays between 30-100μm. Therefore, smaller particles concerning for airborne transmission were not formally assessed. However, the use of both the intact and VENT masks produced significant relative reductions in contamination suggesting that these barrier methods would still be beneficial in the outpatient setting. Conversely, our maximum calculated droplet size could have potentially represented the coalescence of several smaller droplets. With respect to our surgical simulations, it is possible that the microdebrider was capable of producing aerosols

below our estimated size detection limit of 20μm however this will need to be tested in further studies. Finally, our experimental design did not probe aerosol generation during thermal procedures or the use of suction drills.

Our data confirm that the use of high-speed drills appears to be the single greatest risk factor for potential infectious aerosolization during endonasal surgery even when activated for only several seconds. The pooling of fluid appeared to promote increased aerosolization when drilling and thus continuous nasopharyngeal suction using a flexible catheter may be advantageous to both reduce fluid accumulation and direct aerosols posteriorly. Though not formally evaluated, we did not find occlusion and/or obstruction of the nares while drilling to effectively mitigate the risk of contamination. Faced with bony removal in endonasal procedures, surgeons utilize the high-speed drill for convenience, efficiency, and safety. However, in certain high-risk patients (UCS or COVID-19 positive status), consideration of surgical strategies to minimize or even eliminate high speed drill use when feasible may be a prudent cautionary measure based our findings. Within the limits of our experimental design, use of a microdebrider appeared to confer less risk although we would recommend use in the closed position and to ensure the instrument is deactivated prior to removal from the nare. Finally, while the use of electrocautery or ultrasound were not studied, prior literature suggests that these procedures do have the potential to generate virus laden aerosols and should be approached with caution.

Conclusion

Endonasal procedures carry a risk of infectious aerosolization of viral particles such as SARS-CoV-2. Diagnostic nasal endoscopy is not intrinsically aerosol generating. However, the unpredictable triggering of irritative sneezing suggests that practitioners should continue to wear PPE for UCS patients despite the potential benefits of barrier methods. Use of a high-speed surgical drill, even for short intervals, is significantly associated with the potential

for aerosol generation. Prolonged proximity to the patient and the evident concerns related to drilling indicate that endoscopic skull base procedures carry distinct risks beyond classically described AGPs. We recommend that these procedures should be re-classified as “Aerosol Generating Surgeries” and that PPE protocols should reflect the unique dangers of aerosol-based infectious transmission to the skull base team.

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FIGURES

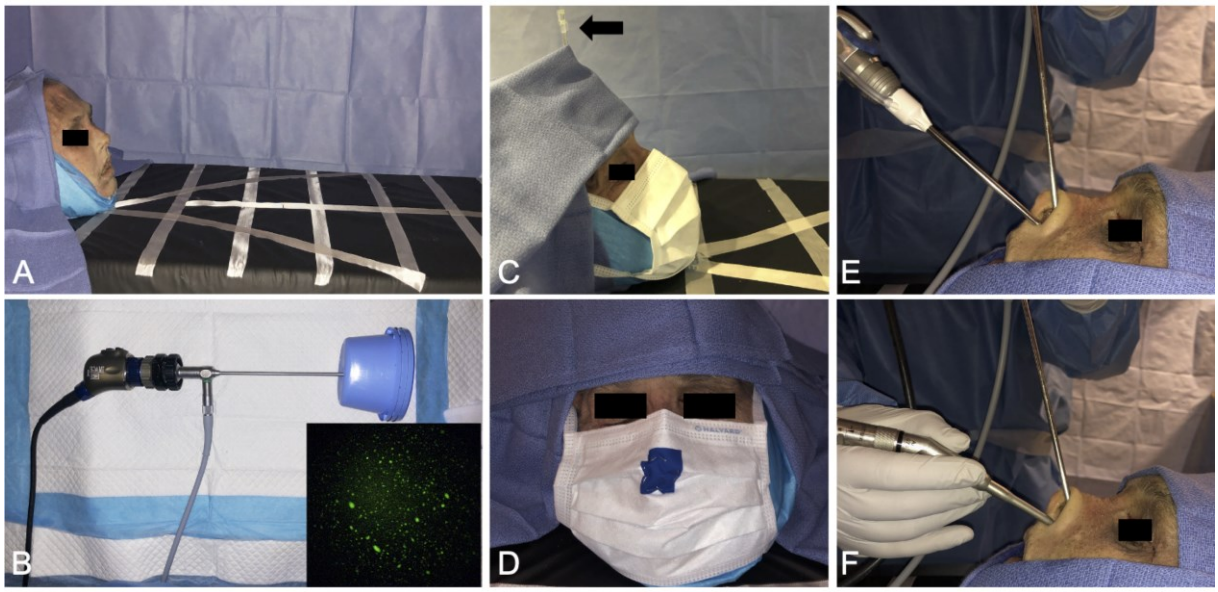

Figure 1. Experimental Setup. A. Upright cadaver head in outpatient endoscopy position in front of aerosolization detection grid. B. 0° Endoscope with blue light filter and occlusion device. Inset demonstrates representative fluorescein-labeled aerosol droplets. C. Upright cadaver head with mask condition demonstrating atomizer (black arrow) placement through cribriform plate into the nasal cavity. D. Upright cadaver head demonstrating VENT mask condition. E. Cadaver head in surgical position demonstrating suction microdebrider condition. F. Cadaver head in surgical position demonstrating 75k rpm drill condition.

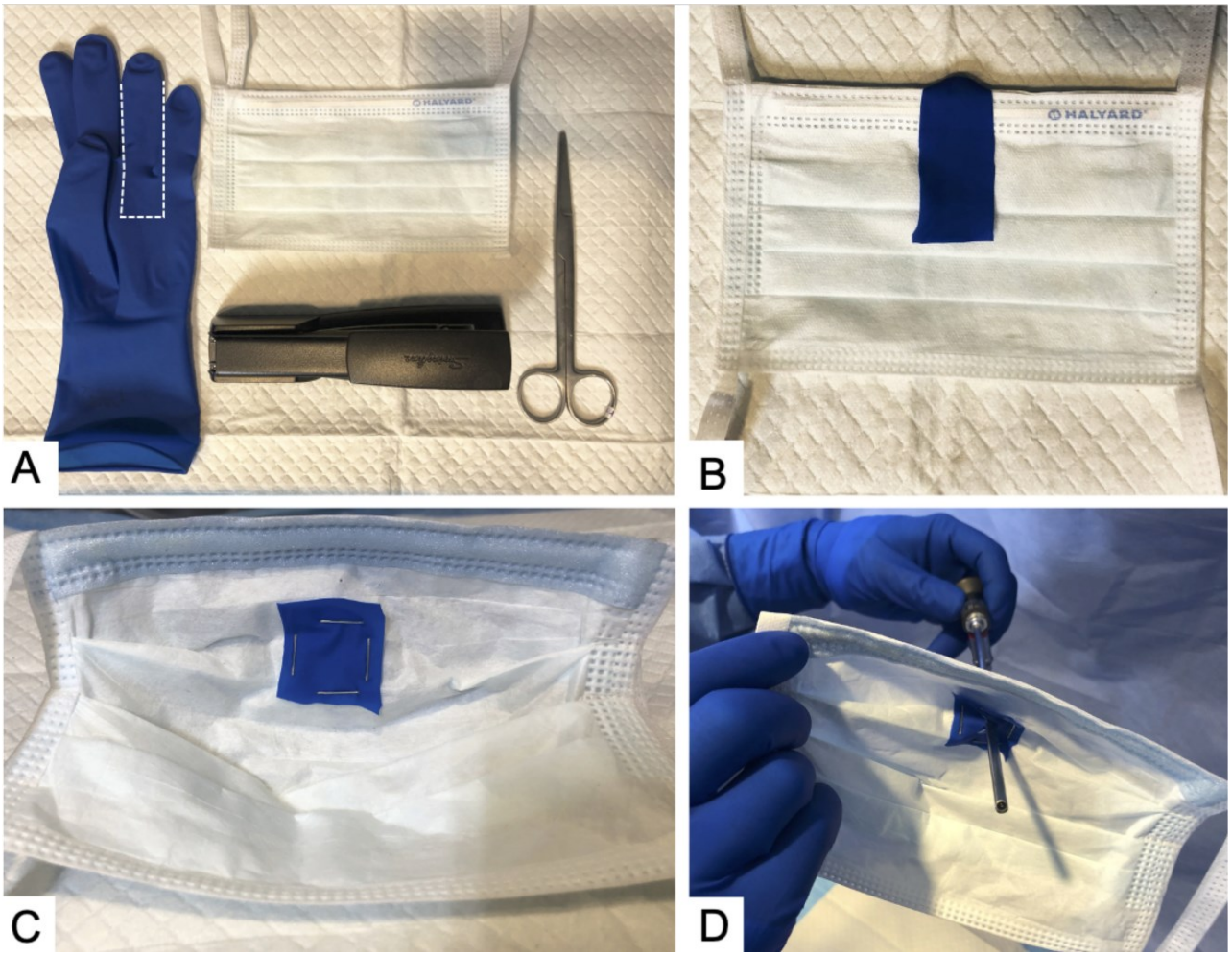

Figure 2. Valved Endoscopy of the Nose and Throat (VENT) mask production. A. Materials needed include a non-latex glove, a standard surgical mask, a stapler, and a scissor. The scissor can be used to cut the finger off the glove. The cut is extended 1 cm into the palm and the sides of the finger are cut leaving the tip intact (see dotted lines). B. The cut glove finger is draped over the nasal bridge with one half of the finger on either side of the mask. C. The stapler is used to staple through both halves of the glove with the teeth (e.g. sharp ends) of the staple facing the outside of the mask (not shown). The tip of the finger is then trimmed as shown. D. A narrow slit is cut through both pieces of glove and the intervening mask which is just large enough to accommodate the shaft of the endoscope.

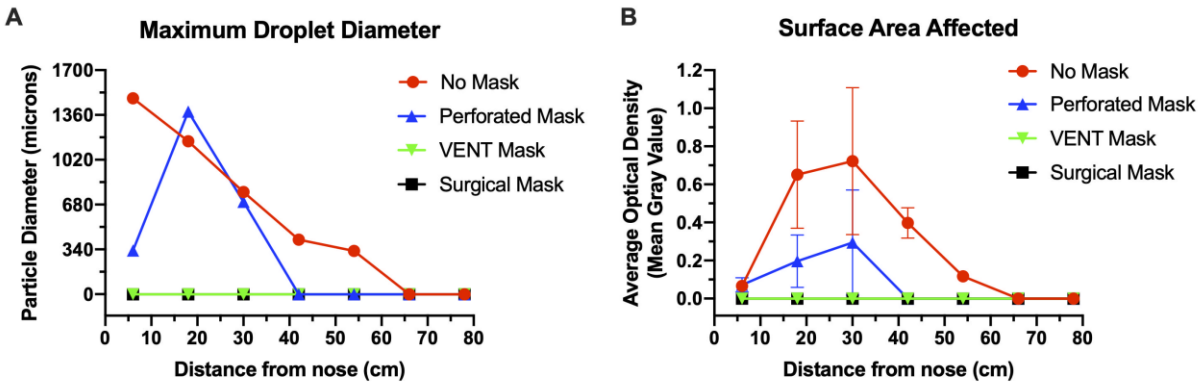

Figure 3. Aerosol distribution in simulated irritative sneeze. A. Maximum droplet diameter was measured at a distance between 6 and 78cm from the nare following activation of the atomizer. Aerosolized droplets were observed in the no mask and perforated mask conditions with decreasing size further away from the nare. No aerosol droplets were detected in the surgical mask or VENT mask conditions. B. Average optical density (mean gray value) of droplet distributions between 6 and 78cm from the nare following activation of the atomizer. No aerosol droplets were detected in the VENT mask condition, a significant difference from both the unmasked and perforated mask conditions at several distance points ($p<0.05$, two-tailed t-test).

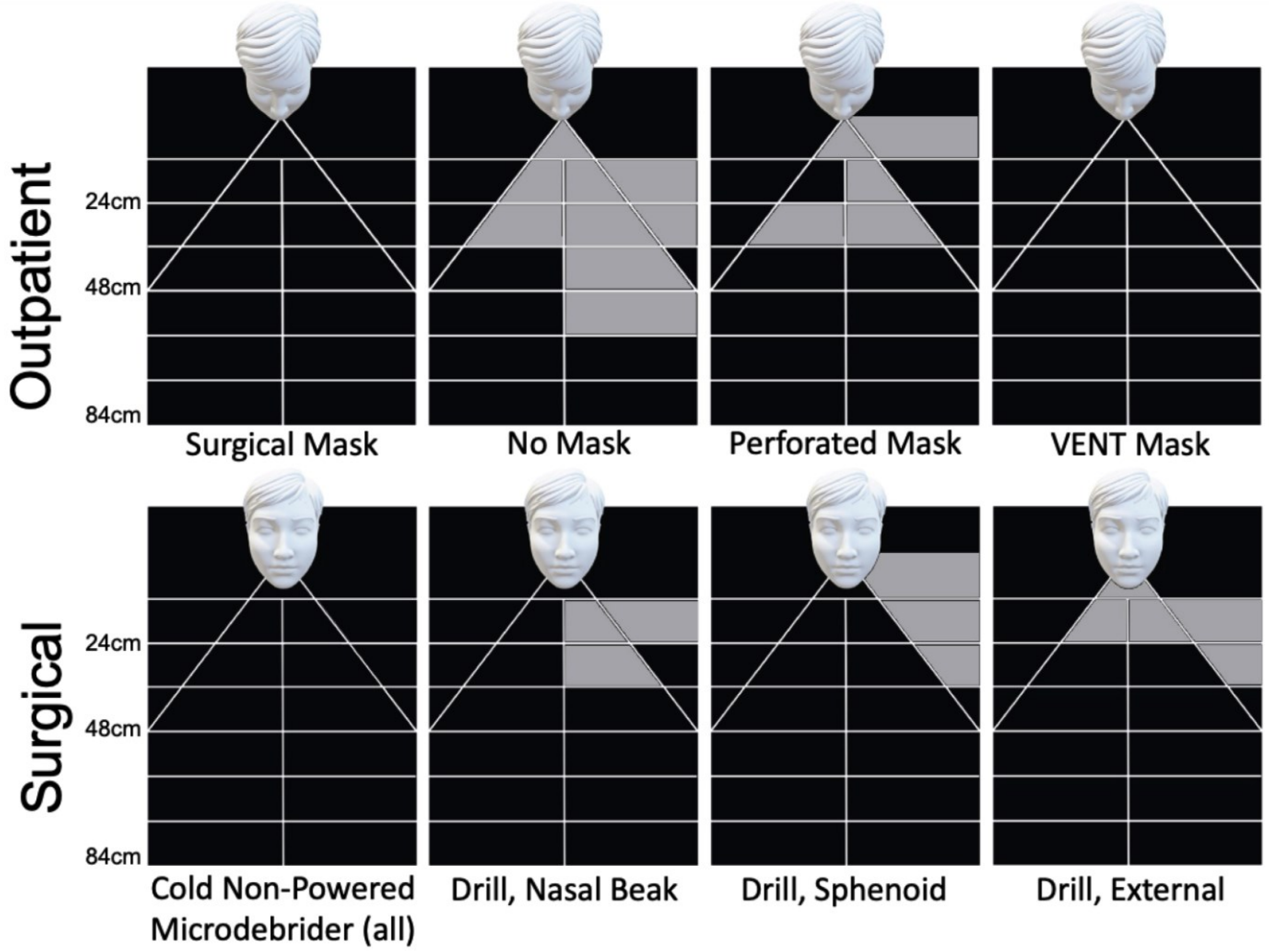

Figure 4. Illustration of geographic spread of aerosol droplets by experimental condition. Grey regions represent areas of any aerosol positivity. Note that among the surgical conditions, use of the drill in all subsites was the only instrument associated with detectable fluorescein contamination.