

Innovations in otorhinolaryngology in the age of COVID-19: A systematic literature review

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Abstract

Objective: Otolaryngologists are at increased occupational risk of Coronavirus Disease 2019 (COVID-19) infection due to exposure from respiratory droplets and aerosols generated during otologic, nasal, and oropharyngeal examinations and procedures. There have been a variety of guidelines and precautions developed to help mitigate this risk. While many reviews have focused on the personal protective equipment (PPE) and preparation guidelines for surgery in the COVID-19 era, none have focused on the more creative and unusual solutions designed to limit viral transmission. This review aims to fill that need.

Data Sources: PubMed, Ovid/Medline, and Scopus

Methods: A comprehensive review of literature was performed on September 28, 2020 using PubMed, Ovid/Medline, and Scopus databases. All English-language studies were included if they proposed or assessed novel interventions developed for Otolaryngology practice during the COVID-19 pandemic. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed.

Results: A total of 41 papers met inclusion criteria and were organized into 5 categories ('General Recommendations for Otolaryngologic Surgery', 'Equipment Shortage Solutions', 'Airway Procedures', 'Nasal Endoscopy and Skull Base Procedures', and 'Otologic Procedures'). Articles were summarized, highlighting the innovations created and evaluated during the COVID-19 pandemic. Creative solutions such as application of topical viricidal agents, make-shift mask filters, three-dimensional (3-D) printable adapters for headlights, aerosol containing separation boxes, and a variety of new draping techniques have been developed to limit the risk of COVID-19 transmission.

Conclusions: Persistent risk of COVID-19 exposure remains high. Thus, there is an increased need for solutions that mitigate the risk of viral transmission during office procedures and surgeries, especially given that most COVID-19 positive patients present asymptotically. This review examines and organizes creative solutions that have been proposed and utilized in the otorhinolaryngology. These solutions have a

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potential to minimize the risk of viral transmission in the current clinical environment and to create safer outpatient and operating room conditions for patients and healthcare staff.

KEYWORDS

COVID-19, Innovations, Inventions, Literature Review, Otolaryngology

INTRODUCTION

As a result of the global Coronavirus Disease 2019 (COVID-19) pandemic, many creative operating room (OR) solutions have been developed and implemented across different surgical specialties to limit the risk of transmission. Clinicians in otolaryngology are at a much higher risk of COVID-19 infection than other specialties due to invasive procedures and examinations of the oral cavity and the upper aerodigestive tract.¹⁻⁴ As otolaryngologic surgical case volumes begin to increase, many of the creative solutions developed during the last few months could prove useful in mitigating the risk of COVID-19 transmission, especially given that more than 30% of COVID-19 infected patients present asymptotically.⁵ The false negative rate for the Polymerase Chain Reaction (PCR) test is unknown, but has been estimated as high as 67% in the asymptomatic period.^{5,6} Additionally, PCR testing in nasopharyngeal and throat swabs may be negative early in the incubation period.⁵ This article reviews some of the clinical pearls that have been described in the literature over the last few months with a specific focus on simple, practical, and inexpensive solutions that have been developed to limit the potential transmission of COVID-19 during aerosol generating procedures (AGPs). It offers suggestions on how these solutions might be specifically utilized by clinicians in our field moving forward.

METHODS

We conducted a rapid systematic literature search to mine the literature for novel, creative, and innovative strategies that help limit the transmission of COVID-19 in the clinic and operating room during otolaryngology procedures. The electronic search was completed on September 28, 2020, using PubMed, Ovid/Medline, and Scopus databases. Titles and abstracts were reviewed to screen out non-relevant articles and the working group reviewed the full text of the remaining articles. These articles were assessed for the following eligibility criteria: English-language papers; articles proposing or assessing novel interventions, techniques, or solutions; articles relevant to AGPs and surgeries conducted on mucosal surfaces; articles which contained novel solutions relevant to otolaryngology practice during the COVID-19 pandemic; and articles published between March 2020 and September 2020.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used for accuracy of reporting (Figure 1).⁷ The search terms utilized for the three databases were: "ENT and COVID-19" "Otolaryngology and COVID-19" "Sterile Technique and COVID-19" "ENT and sterile technique" "Otolaryngology and sterile technique" "ENT and Personal Protective Equipment (PPE)" "Otolaryngology and PPE".

The results of the database searches were screened and analyzed by two authors (L.S. and E.B.M.). Any discrepancies in eligibility and data collection were discussed and resolved. Meta-analysis was not conducted given the mixed nature (original investigations, literature reviews, viewpoints, and general guidelines) of the literature included in this review. Although many of these innovations were subjectively validated, we attempted to evaluate the level of evidence for each proposed intervention using the Oxford Center for Evidence-Based Medicine criteria (Table 1).⁸ Similarly, given the heterogeneity of the studies analyzed, the risk of bias assessment utilizing ROBINS-I (Risk of Bias in Nonrandomized Studies) criteria was performed only where appropriate (Table 1).⁹

RESULTS

Our literature search yielded a total of 1 024 abstracts after the deletion of duplications (Figure 1). Of these, 838 were excluded based on the title and lack of relevance to the focus of this review. The remaining articles (a total of 186) were closely screened using article abstracts. Of those, 64 full-text articles were selected and assessed for eligibility. A total of 41 papers met the eligibility criteria and were organized into 5 categories ('General Recommendations for Otolaryngologic Surgery', 'Equipment Shortage Solutions', 'Airway Procedures', 'Nasal Endoscopy and Skull Base Procedures', and 'Otologic Procedures'). Articles were summarized, highlighting the proposed or evaluated innovation (Table 1). Only published articles were included in Table 1 as part of the official review, although unpublished proposals are mentioned in the discussion if they were found to be particularly innovative. Creative solutions such as application of topical viricidal agents, make-shift mask filters, three-dimensional (3-D) printable adapters for headlights, aerosol containing separation boxes, and a variety of new draping techniques have been developed to limit the risk of COVID-19 transmission.

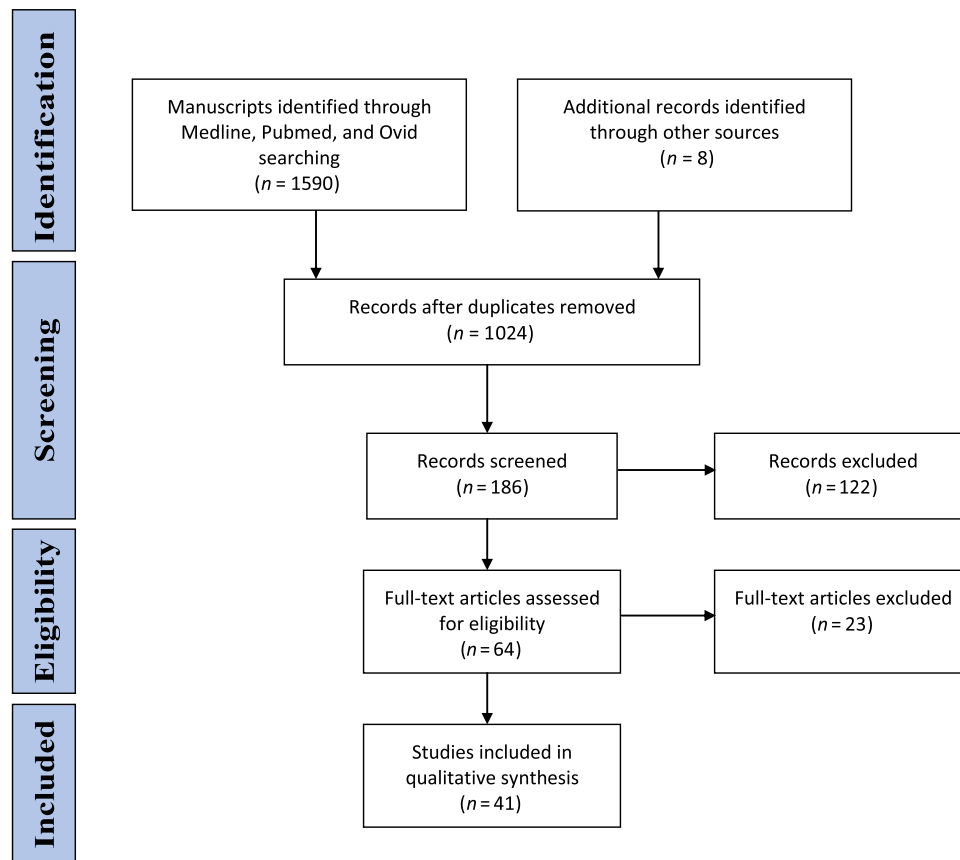


FIGURE 1 PRISMA diagram⁷

DISCUSSION

General recommendations for otolaryngologic surgery

COVID-19 has resulted in the rapid development of general guidelines that have been essential in creating a safer working environment for healthcare workers in otolaryngology. The existence of these protocols is worth mentioning before delving into specific innovations, since these guidelines will underpin care during the pandemic. An article by Xu et al.,⁵¹ provides a review of suggestions to prevent COVID-19 transmission to healthcare workers in otorhinolaryngology. This review spans from minimizing elective surgeries during the outbreak, to the use of Grade II precautions for providers treating febrile patients regardless of their COVID-19 status, and Grade III precautions for AGPs as well as for surgeries that cannot be postponed. They also suggest the use of muscle relaxants during procedures like tracheostomy to prevent coughing and avoid unnecessary droplet spread.⁵¹

During surgery, adhesive dressings should be used to cover nares and mouth if the surgical approach allows.⁶ Electric diathermy, electrocautery, drills, saws, open suctioning and other advanced energy devices create aerosolized biological particles⁵²⁻⁵⁴ or produce possibly infectious smoke.⁵⁵⁻⁵⁷ Interestingly, cadaver work by Workman et al.³⁴ has found that microdebriders do not produce

significant aerosolization³⁴; however, due to concern that this work did not accurately capture microdebrider aerosolization pattern,⁵⁸ most guidelines recommend limiting the use of all powered instrumentation when possible, while ensuring use of appropriate personal protective equipment (PPE) if this instrumentation is necessary.

Although negative pressure chambers are preferred when performing routine examinations on COVID-19 positive or suspected positive patients, these rooms are limited in most facilities. Sayin et al.¹⁰ created a modified negative pressure closet chamber for otolaryngologic examinations. The patient sits in this closet sized chamber (which is connected to an exhaust system in the ceiling with an aspirating fan to create negative pressure and a Bluetooth speaker to allow communication between the patient and the provider), and the examiner performs all endoscopic and laryngeal procedures through gloved access points on one side of the glass. The chamber is also equipped with UV-C sterilization equipment that is used between patients.¹⁰

In a proof-of-concept study, Blood et al.¹¹ found that a COVID-19 Airway Management Isolation Chamber (CAMIC) system—a chamber created by draping a plastic surgical bag over a polyvinyl chloride hollow box frame with fenestrations—was effective in actively removing particulates from smoke and nebulized saline. The CAMIC system, meant to cover the head and chest of a patient,

TABLE 1 Published articles included in the review

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
General recommendations for otolaryngologic surgery	Modified negative pressure closet for endoscopic and laryngeal procedures equipped with UV-C sterilization equipment.	Sayin I, Devecioglu I, Yazici ZM. ¹⁰	Technical report of prototype	Level 5 (mechanism-based reasoning; effectiveness not evaluated) Risk of Bias: N/A	Negative pressure rooms are limited in most institutions; this closet allows for a portable and relatively inexpensive alternative to negative pressure exam rooms.
	COVID19 airway management isolation chamber (CAMIC) for common ENT examinations.	Blood TC Jr, Perkins JN, Wistermayer PR, et al. ¹¹	Preclinical evaluation of prototype: proof-of-concept	Level 4 (case-control study—multi-institutional) Risk of Bias: Moderate (small sample size, variability in test room conditions)	Simulation study using mannequins. Made from plastic surgical bags and a polyvinyl chloride frame with attached suction, this system fits over a patient's head and was effective in removing particulates of smoke and nebulized saline from the chamber.
PVP-I solutions applied preoperatively before upper airway surgery. PVP-I used as nasal and oral irrigation for all patients with suspected or confirmed COVID19 + and healthcare providers after contact with suspected/confirmed COVID19 + patients. 0.5% PVP-I may be used to replace traditional irrigation fluid.		Parhar HS, Tasche K, Brody RM, et al. ¹²	Literature review	Level 3 (literature review without consistently applied reference standards) Risk of Bias: Low-moderate (non-comparability between studies referenced)	PVP-I dramatically reduces viral load and decreases risk of viral transmission during upper airway mucosal surgery. PVP-I has superior anti-virucidal properties against SARS-CoV-2 than hydrogen peroxide does.
		Pelletier JS, Tessema B, Frank S, et al. ¹³	Preclinical evaluation of intervention: proof-of-concept	Level 4 (case-control) Risk of Bias: Low (authors disclose conflicting interests)	
Nasal irrigations have the potential to eliminate viral particles in the nasopharynx.		Mady LJ, Kubik MW, Baddour K, et al. ¹⁴	Technical report of intervention (Letter to the editor)	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	
		Bidra AS, Pelletier JS, Westover JB, et al. ¹⁵	Preclinical evaluation of intervention: comparative	Level 4 (case-control) Risk of Bias: Low	
Nasal irrigations have the potential to eliminate viral particles in the nasopharynx.		Khan MM, Parab SR. ¹⁶	Technical report of intervention	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	
		Farrell NF, Klatt-Cromwell C, Schneider JS. ¹⁷	Technical report of intervention (Viewpoint)	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	Simple nasal irrigation with hypertonic saline (<5% NaCl) may improve mucociliary clearance and thus clearance of the virus. Other additives like PVP-I may be added to these irrigations.

(Continues)

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
	Smartphone enabled wireless otoscope (SEWO) used in telemedicine.	Meng X, Dai Z, Hang C, Wang Y. ¹⁸	Intervention description and observational study (Letter to the editor)	Level 4 (observational/survey study with subjective reference standard; no control) Risk of Bias: Serious (outcome measure was subjective)	Wireless otoscopes are available from multiple e-commerce websites and allow patients to perform a self-otoscopic exam and send those pictures directly to their physician in real-time for diagnosis and management purposes.
Equipment shortage solutions	Ventilator circuit masks created utilizing HEPA and/or anesthesia circuit filters to divert patient exhaled air through the filter.	Convissar D, Berra L, Chang MG, et al. ¹⁹	Technical report of prototype	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	The MAVERiC is created from HEPA filters, facemask, and OR strap. Can be quickly assembled and “fit-tested” in the OR.
	Other reusable masks include commercially available full-face snorkeling masks modified to include FFP2 filters and surgical lights, and reusable half-face respirators typically used in industrial construction.	Liu D, Koo TH, Wong J, et al. ²⁰ Thierry B, Célérier C, Simon F, et al. ²¹ Patel B, Hardman JC, Yang W, et al. ²²	Preclinical evaluation of prototype: proof-of-concept Prototype description and feasibility study Prototype descriptions and observational study with cost analysis	Level 5 (mechanism based reasoning, no control) Risk of Bias: Moderate (small sample size with limited demographics) Level 5 (no formal validation, no control) Risk of Bias: Serious (outcome measures were subjective) Level 5 (no formal validation, no control) Risk of Bias: Low-moderate (outcome measures were subjective for comfort and use of mask; cost analysis had low risk of bias)	These masks are alternatives to disposable N95s and can be quickly assembled from readily available OR equipment. These options were found to be safe, convenient, cost-effective and comfortable alternatives to the disposable N95.
	3-D adapters for headlamps and standard headlamp modification to include shielding.	Viera-Artiles J, Valdiande JJ. ²³ Farneti P, Sorace F, Tasca I. ²⁴	Prototype description and feasibility trials (article is transcript of interview) Prototype Descriptions and Feasibility Trials	Level 5 (mechanism-based reasoning, no formal validation) Risk of Bias: No information Level 5 (mechanism-based reasoning, no formal validation) Risk of Bias: Serious (outcome measured was whether any physician had been contaminated in 2-month trial of use)	3D-printable face shields are not compatible with headlights used by ENTs for routine examinations. The adapter described by Viera-Artiles enables the ENT to use a traditional headlight with a protective 3D-printable face shield. The shield attached to the standard frontal headlamp creates another protective barrier between provider and patient.

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
Airway procedures	Intubation protection tents and boxes designed as aerosol limiting enclosures - typically created from transparent plastic drapes fit over plastic tube scaffolding, for use during intubation.	Canelli R, Connor CW, Gonzalez M, et al. ²⁵	Preclinical evaluation of prototype: proof-of-concept (Letter to the editor)	Level 4 (case control simulation) Risk of Bias: Moderate (simulation not validated for mechanics of true cough or particle size distribution)	These 3-sided boxes shield providers during intubation. In one design, a 2 L-shaped iron frames are used to create a flexible box around the patient over which a plastic sheet can be draped. Holes are cut into the side to allow passage of the provider's hands. Preliminary studies into the safety and effectiveness of this particular innovation indicate that without proper training, use may result in increased intubation time and damage to conventionally worn PPE.
		Kearsley R. ²⁶	Technical report of intervention (Letter to the editor)	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	
		Begley JL, Lavery KE, Nickson CP, et al. ²⁷	Preclinical evaluation of prototypes: comparison	Level 4 (case control) Risk of Bias: Low	
	Negative-pressure aerosol covers for tracheotomy	Bertroche JT, Pipkorn P, Zolkind P, et al. ²⁸	Prototype description and case report	Level 5 (case report with no control) Risk of Bias: Moderate (outcomes were subjective - ease of use; efficacy not validated)	Patient is covered with a clear plastic drape attached to a smoke evacuator and a high-efficiency particulate air filtration unit to create a negative pressure space. Holes were cut in the plastic drape for the surgeon's hands. Set up takes less than 5 minutes.
	Home-made protective screens, "suspension boxes", and tents for use during tracheostomy, laryngeal procedures, and emergency bronchoscopies.	Cordier PY, De La Villeon B, et al. ²⁹	Technical report of prototype	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	Cordier et al. use metal external fixator equipment to create a box frame which is then wrapped with single-use sterile C-arm cover and placed over the surgical field.
		Pollaers K, Herbert H, Vijayasekaran S. ³⁰	Intervention description and case series observational case series (n = 8)	Level 4 (case series; outcomes observational, lack of generalizability) Risk of Bias: Moderate - (outcome measures subjective - surgeon comfort and ability)	Pollaers et al. designed a polymethyl methacrylate box with 3 open sides - box and patient are covered with plastic sheet secured to OR table and to the surgeon's gown at waist height. Surgeon's arms remain under sheet at all times. Patient is intubated and extubated under sheet.
		Francom CR, Javia LR, Wolter NE, et al. ³¹	Preclinical evaluation of prototypes: proof-of-concept	Level 5 (mechanism-based reasoning) Risk of Bias: Moderate (lack of objective validation)	The draping system described by Francom utilizes a smoke evacuator secured to the draping system to limit escape of

(Continues)

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
	Masks designed to be worn by patients in the clinic during AGPs like flexible laryngoscopy.	Hoffman HT, Miller RM, Walsh JE, et al. ³²	Prototype description and observational study (n = 30)	<p>Level 4 (mechanism-based reasoning, lack of comparison of efficacy when compared to other methods)</p> <p>Risk of Bias: Moderate (Tolerability measured subjectively through Likert scale)</p> <p>Level 5 (mechanism-based reasoning with simulation study)</p> <p>Risk of Bias: Moderate (ease of use and feasibility evaluated, no quantitative evaluation of droplet spread)</p>	<p>aerosolized particles during airway procedures.</p> <p>Negative Pressure Face Shield (NPFS) consists of a transparent barrier with two instrument ports and a continuous suction.</p> <p>The modified mask by Narwani et al. is an altered adult endoscopy mask with filter and slit to allow passage of the laryngoscope.</p>
		Narwani V, Kohli N, Lerner MZ. ³³	Preclinical evaluation of prototypes: proof-of-concept		
Innovations for nasal endoscopy and skull base procedure	A modified Valved endoscopy of the nose and throat (VENT) mask - to be worn by patient.	Workman AD, Welling DB, Carter BS, et al. ³⁴	Preclinical evaluation of prototypes: proof-of-concept	<p>Level 4 (case-control simulation)</p> <p>Risk of Bias: Moderate (cadaver study and lab setting may not accurately reflect in vivo OR conditions)</p>	The sides of the single finger of a non-latex glove were cut vertically while leaving the tip intact. This cut finger is draped over the internal and external sides of a standard surgical mask, staples secure it in place. A slit in the mask allows passage of the endoscope. The mask is placed on the patient. This study was done on a cadaver model.
	Nasopharyngeal suctioning via rigid suction placed in the contralateral nostril to limit particulate spread during sinonasal drilling.	Workman AD, Xiao R, Feng A, et al. ³⁵	Preclinical evaluation of intervention: comparison	<p>Level 4 (case-control simulation)</p> <p>Risk of Bias: Moderate (cadaver study and lab setting may not accurately reflect in vivo OR conditions)</p>	These studies were conducted in the cadaver model. Suctioning is effective in reducing aerosol contamination.
	Negative pressure systems created from modified ambu masks (negative airway respirator or NAPR) or negative-pressure otolaryngology viral isolation drapes (NOVID).	Khoury T, Lavergne P, Chitgutti C, et al. ³⁶	Preclinical evaluation of prototypes: proof-of-concept	<p>Level 4 (case-control simulation)</p> <p>Risk of Bias: Moderate (incense sticks used may not accurately reflect aerosol/smoke created in OR; difficult to quantitatively measure)</p> <p>Level 4 (case study)</p>	<p>NAPR consists of an Ambu mask with a small hole drilled into the front fitted with suction. Tested in the cadaver model only.</p> <p>The NOVID consists of a plastic drape suspended over patient's head and surgical field and</p>

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
		David AP, Jiam NT, Reither JM, et al. ³⁷	Prototype description and observational study (n = 4 patients)	Risk of Bias: Moderate (no control group; dye may not adequately reflect droplet behavior)	connected to a smoke detector suction. It was found to be effective in limiting contamination from speed drilling during endonasal surgery in multiple patients.
	SPIWay® Endonasal sheaths with flexible suction were used to mitigate aerosol dispersion during endoscopic drilling.	Dharmarajan H, Freiser ME, Sim E, et al. ³⁸	Preclinical evaluation of prototypes: comparison	Level 4 (case-control simulation) Risk of Bias: Moderate (cadaver study and lab setting may not accurately reflect in vivo OR conditions)	Study consisted of field contamination survey, simulation of aerosol dynamics, and evaluation of particle generation and spread under various mitigation measures. Suction was found to eliminate all detectable aerosols. Studies conducted in cadaver models only.
	A variety of masks have been proposed that are specifically designed for patients to wear while undergoing nasal endoscopy. All of these masks have openings to allow for the passage of a flexible endoscope while maintaining a barrier between provider and patient.	Anon JB, Denne C, Rees D. ³⁹	Preclinical evaluation of prototypes: proof-of-concept	Level 4 (case simulation) Risk of Bias: Moderate (only gives overview of larger droplets; no control)	Enhanced Protection Face Shield (EPFS) essentially creates a tab locking plastic box around the patient's head. Proof-of-concept study only.
		Curran J, Calder N, Yaneza M, et al. ⁴⁰	Technical report of prototype	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	Curran et al's design utilizes a modified CPAP connector and 'closed' anesthetic facemask.
		Davies JC, Chan H, Gilbert RW, et al. ⁴¹	Preclinical evaluation of prototypes: comparison	Level 4 (case study - simulation) Risk of Bias: Moderate (atomization may not properly replicate cough; no control; dye grossly visualized)	The majority of Davies et al.'s designs are unusual in that they use disposable surgical masks with 3D printed attachments that perforates the mask to allow endoscope passage.
	Changing the way you approach the patient: "Back approach to the patient for endoscopic exams" to limit examiner's exposure to airborne transmission.	Di Maio P, Traverso D, Iocca O, et al. ⁴²	Technical report of intervention	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	The examiner positions himself behind the patient and faces the monitor, thus decreasing the examiner's exposure to airborne transmission of SARS-CoV-2 virus.
Otologic procedures	A variety of draping methods have been developed to limit aerosol spread during mastoidectomies.	Gordon SA, Deep NL, Jethanames D. ⁴³	Prototype description and case report	Level 4 (case report - no control) Risk of Bias: Moderate (outcomes subjective - surgeon perceived comfort and efficacy)	Most of these methods use commonly available surgical drapes and other equipment traditionally present in the Operating room.

(Continues)

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
		Carron JD, Buck LS, Harbarger CF, et al. ⁴⁴	Preclinical evaluation of prototypes: proof-of-concept	Level 4 (case simulation) Risk of Bias: Moderate (may be technically too difficult to apply to live situation; no control; cadaver study; outcomes were grossly assessed)	In Gordon et al.'s design a plastic drape placed around normally draped exoscope to create a small tent. Surgeons hands remain and all instrument exchanges occur below tent. Allowed surgeon to comfortably wear 3D glasses without face shields.
		Panda NK, Agarwal G, Hage N, et al. ⁴⁵	Intervention description and case report	Level 5 (mechanism-based reasoning) Risk of Bias: N/A	Carron et al used two clear drapes attached to lens cap apparatus of microscope and to Mayo stand at patient's head. Mastoidectomy performed under both drapes with full surgical field visible. Studies conducted on cadavers in standard OR.
		Chen JX, Workman AD, Chari DA, et al. ⁴⁶	Preclinical evaluation of prototypes: proof-of-concept	Level 4 (case-control simulation) Risk of Bias: Moderate (cadaver study and lab setting may not accurately reflect in vivo OR conditions)	Panda et al. and Chen et al. both created tent-like structures to protect against aerosol generation in mastoidectomy drilling.
		Chari DA, Workman AD, Chen JX, et al. ⁴⁷	Preclinical evaluation of interventions: comparison	Level 4 (case-control simulation) Risk of Bias: Moderate (cadaver study and lab setting may not accurately reflect in vivo OR conditions)	Chiari evaluated OtoTents and found that OtoTents in addition to suction provided the best protection.
	Half-face mask and safety goggles to reduce vision interruption while still maintaining proper PPEE during otologic surgery.	Lawrence RJ, O'Donoghue G, Kitterick P, et al. ⁴⁸	Preclinical evaluation of prototypes: comparison	Level 4 (case-control simulation) Risk of Bias: Moderate (ex-vivo study in temporal bones; subjective outcomes in comfort and breathability, ease of donning – participants vital measures were also recorded adding to the validity)	Spoggles are foam-lined safety goggles.
	Use of a CAMIC-Ear isolation chamber for otologic surgeries.	Tolisano AM, Blood TC Jr, Riley CA, et al. ⁴⁹	Prototype intervention description and case report/feasibility study Only one case, patient tested negative after, ergonomically satisfactory	Level 4 (case report) Risk of Bias: Moderate (measurement of efficacy included patient testing negative after; no control; single patient undergoing	A system made of PVC fenestrated pipes shaped into a cube that covers patient head and shoulders and is attached to the sterile microscope drape. Evaluated on a single patient undergoing

TABLE 1 (Continued)

Item	Novel techniques and innovations	Citation	Article type	Level of evidence and risk of bias	Comments
	Transcanal endoscopic ear surgery as an alternative to traditional ear examining methods avoids the AGP potential involved in middle ear and mastoid surgeries.	Ayache S, Kutz W, Isaacson B, et al. ⁵⁰	by operating surgeon No control Technical report of proposed intervention	outcomes subjective – ergonomic use) Level 5 (mechanism-based reasoning) Risk of Bias: N/A	mastoidectomy and was considered safe and satisfactory by users.

has suction attached to one edge and an oxygen supply at the other end, creating a laminar flow to remove particulate matter. The authors suggest that this type of system could be utilized as an additional PPE barrier during common AGP in otolaryngology.¹¹

One simple intervention in common otolaryngologic surgeries is the pre-operative application of topical agents with virucidal activity. In a literature review, Parhar et al.¹² found that 0.23% to 7% Povidone-iodine (PVP-I) solutions were effective in reducing viral loads of the coronaviruses that cause severe acute respiratory syndrome (SARS-CoV1) and Middle East Respiratory Syndrome (MERS-CoV). This has been confirmed more recently by Pelletier et al.¹³ when they directly evaluated nasal and oral antiseptic formulations of PVP-I for virucidal activity against SARS-CoV-2. They found that a variety of concentrations completely inactivated the virus at a 60 second exposure time.¹³ Mady et al.¹⁴ also propose a strategy utilizing PVP-I as both a nasal irrigation and an oral/oropharyngeal wash for surgical and non-surgical patients with suspected or confirmed COVID-19 infection, as well as for healthcare providers prior to and after contact with suspected/confirmed COVID-19 positive patients. PVP-I has been directly compared to hydrogen peroxide, another virucidal topic agents, and has been found to be more effective at a variety of dilutions.¹⁵ Given this data, Khan and Parab¹⁶ propose the substitution of 0.5% PVP-I for all irrigation fluid used during otolaryngologic procedures, particularly for the irrigation needed for drilling procedures like mastoidectomies.

In a viewpoint piece published in JAMA, Farrel et al.¹⁷ promote the use of hypertonic saline (<5% sodium chloride) irrigations to improve mucociliary clearance and suggest that other additives, like PVP-I, may aid in eliminating viral particles in the nasopharynx prior to active infection.¹⁴ These safe to use and readily available PVP-I solutions may reduce the risk of COVID-19 aerosolization and transmission in upper airway mucosal surgery.¹²⁻¹⁷

A major change in Otolaryngologic practice during the COVID-19 pandemic has been the dramatic increase in utilization of telemedicine for patient visits. While this review does not cover the different ways that telemedicine has been used in ENT patient care, it did uncover one particularly interesting innovation used in some telemedicine ENT practices: a smartphone-enabled wireless otoscope (SEWO). Meng et al.¹⁸ provide an overview of this technology and report high patient satisfaction in a small study conducted in China. The device, a Mebird M9pro wireless otoscope, can be purchased online from multiple e-commerce websites and patients can perform a self-otoscopic exam, the images of which are sent to their physician via a downloaded app. Otolaryngologists could make diagnoses and provide real-time feedback to their patients, successfully diagnosing conditions like acute otitis media, tympanic membrane perforation, and cholesteatomas.¹⁸

Equipment shortage solutions

Two different types of solutions have emerged to solve equipment shortages: (1) stratification of PPE needs for different procedures,

and (2) creation of new PPE from readily available supplies. Although not a direct focus of this literature review, the stratification of PPE is worth mentioning before delving into the innovative solutions involving the creation of new PPE. Chow et al.⁵⁹ found that droplet contamination was highest and most widespread during osteotomies, indicating that these types of surgeries warrant the most advanced PPE, while transoral robotic surgeries have the lowest risk of droplet contamination, suggesting that less stringent PPE is sufficient for providers during these procedures.

Many institutions developed multidisciplinary approaches for the evaluation and management of certain otolaryngologic conditions. Shanti et al.⁶⁰ developed a risk stratification approach for evaluating patients with oral potentially malignant disorders. Utilizing criteria like new patient status and presence of “high” or “low” risk features, they have developed a pathway that directs providers towards recommendations of either telemedicine or in-person encounter, PPE usage, tissue handling, and topical preparation of oral mucosa.⁶⁰

Multiple makeshift filters and shields have been created to limit the risk of viral transmission. Convissar et al.¹⁹ designed a makeshift mask filter they call the Modified Airway from VEntilatoR Circuit (MAVerIC), which is assembled from a standard adult anesthesia breathing circuit with high-efficiency particulate air (HEPA) filters, a facemask, and a rubber operating room head strap typically used to stabilize a patient's head. This mask can be quickly assembled and “fit-tested” in the OR to ensure absence of a leak and efficacy of the mask. Although their mask has yet to undergo comparative studies with the N95 mask, if equipment availability continues to be a limiting factor in surgical procedures, the use of these types of makeshift devices could be considered, especially during lower-risk procedures. Similarly, Liu et al. created an adaptor using a 3-D printer that allows elastomeric respirators to interface with anesthesia circuit filters, diverting all exhaled breaths through the filter. They suggest this type of filter may serve as an alternative to disposable N95 respirators.

Thierry et al.²¹ modified an EasyBreath snorkeling mask with special adapters that are made using a 3-D printer and allow for the clipping on of the fragment of an FFP2/N95 face mask as well as an upper adapter that would enable the attachment of a surgical light. Surgeons performing bedside tracheostomy reported greater comfort, visibility, and feelings of safety when using the adapted snorkeling mask than they did when using a headshield and a Filtering Face Piece (FFP)/N95 face mask.²¹ No formal evaluation of the efficacy of this mask has yet been conducted.

Another solution to N95 mask shortages are the use of modified reusable N95 equivalents. Patel et al.²² conducted a study across three separate institutions on the use of a reusable half-face respirator (the Sundstrom SR 100 respirator) typically used in industrial settings, in 72 head and neck surgery cases. They found this mask to be a safe, convenient, and cost-effective alternative to the disposable FFP3 masks.²² Although not yet published, it is worth mentioning the innovative mask developed by Franco et al.⁶¹ This mask is the modified ENVO[®] mask by SleepNet to allow for suction to create a negative-pressure environment around the nose and mouth of the patient. A small incision is made in the front part of the

filter to allow for scope passage to prevent aerosolization during nasopharyngolaryngoscopy.⁶¹

Otolaryngologists rely on headlights to perform naso/oropharyngeal examinations. Currently, no commercially available face shields are compatible with the headlight traditionally utilized in these procedures. Viera-Artiles and Valdiande²³ designed an adapter made using a 3-D printer, which utilizes a transparent sheet to create effective barrier protection while the headlight is in use. Farneti et al.²⁴ also developed a modification to the standard frontal headlight by applying a flexible custom-made clear laminated “shield” which fixes to the scaffolding of the headlight, providing a barrier between provider and patient. Additionally, they also propose a liftable protective shield of methacrylate which can be applied to the ENT examination chair. The shield is designed with holes in the front panel to allow the provider to introduce his hands, apertures on the side to allow the introduction of instruments, and a posterior aperture for the passage of air.²⁴

Airway procedures

Intubation of COVID-19 infected patients is a procedure that carries a high risk of viral transmission.⁶² Some difficult airways require both an anesthesiologist and an otolaryngologist. One of the novel devices for intubation is the aerosol box, which shields the provider from aerosol particles. The device is a transparent plastic box with an opening on one side, which allows it to fit over the patient's chest and neck while the opposite side has two small holes for the provider's hands.²⁵⁻²⁷ Although this box may increase intubation time and there is a learning curve for the providers to avoid damage to PPE and other challenges during its use, it does present a simple solution that may limit transmission risk.²⁷

Following intubation, many COVID-19 patients require tracheostomy. A novel solution developed by Bertoche et al.²⁸ involves a negative-pressure aerosol cover made out of clear plastic drape with cuts in the drape for the surgeon's hands. The patient is covered with it, and a smoke evacuator and high-efficiency particulate air filtration unit is used to create negative-pressure space.²⁸ Other tracheostomy solutions include Cordier et al.'s homemade protective screen. Using metal external fixator equipment, they created a box-shaped frame which they then wrapped in a single-use clear and sterile C-arm cover. The dimensions could be adjusted to each individual patient, and the materials are inexpensive and commonly available in most ORs.²⁹

Pollaers et al.³⁰ recommend the use of a “suspension box” in the performance of supraglottoplasties, injection laryngoplasties, and emergency bronchoscopies in the pediatric population. The suspension box is a polymethyl methacrylate [Perspex, Perspex International] box with three open sides. During the procedures, the box and the patient are covered in a transparent plastic sheet secured to the operating table and to the surgeon's gown at waist height, with the surgeon's arms under the sheet.³⁰ Francom et al.³¹ describe a similar barrier method with the creation of surgical tents for the containment

of droplets and aerosolized particles during unsecured airway procedures. They use three disposable drapes, one covering the bed, one covering the patient's body, and one suspended over the patient's head and chest. An ultrafiltration smoke evacuator is secured to the drape on the patient's chest and an ether screen or mayo stand is used to suspend the third drape.³¹

For flexible laryngoscopy, a variety of face masks and shields have been developed to limit transmission risk. In a cohort study, Hoffman et al.³² tested a prototype of a negative pressure face shield (NPFS) in the clinical setting. The NPFS consisted of a transparent acrylic barrier with two anterior instrumentation ports and a side port to which continuous suction was applied. In their assessment of thirty patients, all subjects reported excellent tolerance and the mask succeeded in limiting the dispersion of aerosols.³² The modified endoscopy mask developed by Narwani et al.³³ for flexible laryngoscopy consists of an adult endoscopy face mask with 5-mm endoscopy port, a hook ring, a heat and moisture exchanger with viral filter, and a face mask harness. Using a scalpel, a 3-mm slit was created in the central silicone membrane of the endoscopy mask. This allows for the passage of the flexible fiberoptic laryngoscope. In mannequin studies, this modified mask allowed for the easy maneuverability of the scope and the visualization of the subglottis.³³

Nasal endoscopy and skull base procedures

Endoscopic endonasal procedures present significant infection risk as a result of high nasal viral titers and aerosolization during endonasal instrumentation. Although one review concluded that nasal endoscopy alone does not generate aerosols, coughing and sneezing (common occurrences during these procedures) may result in droplet transmission.³ High-powered instrumentation, especially the use of high-speed drills, increases the spread of certain viral particles.^{3,52,54} Viable viral particulates, including those for Human Immunodeficiency Virus (HIV) and Human Papillomavirus (HPV), have been found in aerosols generated by surgical power instruments or in smoke samples from CO₂ laser ablation.^{55-57,63-65} Endonasal use of high-powered instruments must be limited to cases where it is absolutely necessary with high-level PPE worn by all individuals in the room.

Workman et al.³⁴ created a novel mask that could limit transmission, a modified valved endoscopy of the nose and throat (VENT) mask, which uses a standard surgical mask and the finger of a non-latex glove. The glove finger with cut sides is draped over the nasal bridge with one half of the finger on either side of the mask and both sides of the glove finger stapled to the mask (sharp ends of staples facing away from the patient). A narrow slit is cut through both pieces of the glove to accommodate an endoscope, providing significant reduction in aerosolization. This solution was only tested on a cadaver model, which may not adequately capture real-life aerosolization as it does not account for the air flow rates in the local environment.^{34,58} In other cadaver experiments, Workman et al.³⁴ found that the use of nasopharyngeal suctioning via a rigid suction in

the contralateral nostril minimizes airborne particulate spread during simulated sinonasal drilling and cautery.

Like Workman et al.,³⁵ Khoury et al.³⁶ also evaluated a variety of masks and their ability to limit small-particle escape from skull base procedures conducted in cadaver studies. They found that their negative airway respirator (NAPR), designed by drilling a small hole in the plastic bottom of a standard Ambu mask and inserting a suction tubing, allowed no particles to escape.³⁶ Dharmaraian et al.³⁸ conducted similar studies in cadaver models to evaluate the efficacy of SPIWay[®] Endonasal sheaths in mitigating aerosol dispersion caused by endonasal drilling. These endonasal sheaths are typically used to reduce mucosal trauma during endoscopic procedures and to avoid contaminating scope lenses with surgical debris. When a flexible suction was inserted in addition to the SPIWays[®], no aerosols were detected during drilling.³⁸

David et al.³⁷ developed a negative pressure system and isolation drape to minimize droplet spread during endoscopic skull base and transoral surgeries. Their system, the negative-pressure otolaryngology viral isolation drape (NOVID), consists of a plastic drape suspended over the patient's head and surgical field (a Lone Star ring retractor was attached to a laparoscopic Bookwalter retractor holder to suspend the drape) with a smoke detector suction within the chamber. In a study evaluating the chamber's effectiveness in patients undergoing prolonged endonasal surgery with high speed drilling, they could keep aerosol and droplet contamination to a minimum, as measured by fluorescein.³⁷

A variety of other masks have been created for patients to wear as they undergo flexible fiberoptic endoscopy in the age of COVID-19. Anon et al.³⁹ designed an enhanced protection face shield (EPFS) that involves a polyethylene terephthalate thermal plastic sheet suspended from a foam headband – there are integral tab closures on the sides and an inferior shelf with a double tab locking system. Two stellate openings allow the passage of the flexible endoscope into the nares. In a proof-of-concept study, the EPFS outperformed traditional face shields in its ability to contain contaminants and protect examining personnel from simulated coughing.³⁹ Another similar mask was developed by Curran et al.⁴⁰ for patients to wear during fiberoptic nasoendoscopy. Curran et al.'s design involves an anesthetic 'closed' facemask, filter, DAR connector (an L-shaped device with a closeable hole for instruments), and a reusable harness attachment for continuous positive airway pressure (CPAP). A small hole is made with a thick needle in the DAR connector, through which the endoscope can pass. The mask is then inverted to align the hole with the nostrils instead of the mouth and secured in place with the CPAP harness. The authors promote the devices simplicity, reproducibility, and potential to reduce viral transmission in the outpatient setting.⁴⁰

Davies et al.⁴¹ created three different types of 3-D printed endoscopy masks: (1) a reusable mask made of photopolymer resin with a side port, (2) a disposable mask using a 15-mm endotracheal tube connector and swivel adapter, and (3) the disposable mask with a 3-D printed adapter that perforated the mask and would allow passage of the endoscope. The authors also designed a 3-D printed

hexagonal fastener system with threaded nut and bolt. All three masks prevented the spread of gross droplets (visualized by fluorescent dye) after a simulated cough. Normal PPE without one of these masks in place resulted in broad spread of fluorescent dye droplets.⁴¹

Rather than focus on masks or barriers in endoscopic procedures, Di Maio et al.⁴² took a different approach. They describe the "Back approach to the patient" for endoscopic exams, where the examiner positions himself behind the patient and faces the monitor, thus decreasing the examiner's exposure to airborne transmission of the virus.⁴² Although simple, they suggest that small variations like this may prove effective in limiting the spread of COVID-19 in the clinical environment.

Otologic procedures

There is a known risk of COVID-19 viral transmission during otologic procedures due to the continuity of middle ear passages with the virus laden nasopharynx and use of high-speed instrumentation and microscopy, with the latter presenting a challenge in terms of its use while wearing mandated PPE.^{52,54,66} Similar to draping approaches described by Bertoche et al. and Poallers et al. during tracheostomy and laryngoscopy, a variety of draping procedures have been developed for otologic surgeries. Gordon et al.⁴³ describe a plastic sterile drape with adhesive placed around the normally draped exoscope and enclosed around the sterile field to create a small tent with the surgeon's hands placed beneath the tent. This allowed the team to forego face shields and utilize three-dimensional glasses as the only eye protection effectively avoiding the distortions caused by the curved shape of face shields over three-dimensional glasses when looking through the microscope.⁴³

Similarly, Carron et al.⁴³ designed a drape system to control droplet spray during mastoidectomy with the attachment of two different clear drapes to the lens cap apparatus of their microscope. Both of these drapes are stretched over a Mayo stand at the patient's head with an additional clear drape attached to the surgical drape over the patient's chest area.⁴⁴ Other draping methods developed for otologic surgery include Panda et al.'s draping method where transparent surgical drapes attached to the microscope lens and to a Gottingen Laser support and to the operating table create a tent-like structure over the patient⁴⁵ and Chen et al.'s similar use of the OtoTent to create a barrier drape during mastoidectomy.⁴⁶ Chiari et al.⁴⁷ evaluated two surgical drapes, OtoTent 1 (a drape sheet affixed to the microscope) and OtoTent 2 (a custom-structured drape that enclosed the surgical field with special ports). Without the addition of suction, mastoid drilling resulted in aerosols above baseline levels with OtoTent 1, but not with OtoTent 2. With the addition of suction, both tents prevented aerosol escape.⁴⁷

As discussed, one major issue with otologic surgery is the challenge of visualization when wearing all required PPE. Lawrence et al.⁴⁸ tested a variety of methods to reduce vision interruption during cochlear implantation. They found that an ensemble of a

half-face mask and safety "spoggles" (foam lined safety goggles) had superior clinical performance, allowing the best visualization during microsurgery.⁴⁸

Other innovations for otologic procedures include the CAMIC-Ear isolation chamber by Tolisano et al.⁴⁹ Like the CAMIC system described by Blood et al., this system is created using polyvinyl chloride (PVC) fenestrated pipes that are shaped into a cube and placed around the patient's head and shoulders in a sterile fashion. The microscope drape is attached to the microscope as usual, and then reversed over the CAMIC frame. Two cut-outs are made for the surgeon's hands and scrub technician's hands. This system was evaluated on a single patient undergoing mastoidectomy and was considered safe and satisfactory by users.⁴⁹

Finally, temporary changes in standard of practice may be one way that surgeons mitigate the spread of coronavirus. Ayache et al.⁵⁰ propose the use of transcanal endoscopic ear surgery (TEES) as an effective alternative to address many otologic conditions while also avoiding the AGP potential involved in middle ear and mastoid surgeries. TEES also allows for more comfortable use of eye protection, which is normally limited by the otologic microscope.⁵⁰

CONCLUSIONS

A number of innovative yet practical strategies were developed in response to COVID-19 pandemic to mitigate the risk of transmission during otolaryngologic exams and procedures. These strategies may continue to benefit otolaryngologists moving forward since it is unclear at this time when the virus will stop posing a threat to the health of patients and healthcare providers. This review can serve as a resource for otolaryngologists and for practitioners in other fields by providing them with useful solutions that may serve to protect them and their patients.

CONFLICT OF INTEREST/FINANCIAL DISCLOSURES

None

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