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SYSTEMATIC REVIEW

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One year into the COVID-19 pandemic: What do we know so far from studies assessing risk and mitigation of droplet aerosolisation during endonasal surgery? A systematic review

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Abstract

Objectives: As we pass the anniversary of the declaration of a global pandemic by the World Health Organisation, it invites us to reflect upon the inescapable changes that coronavirus has wrought upon ENT and, in particular, rhinological practice. As it remains unclear when we will emerge from the shadow of COVID-19, a critical analysis of the evidence base on both the assessment and mitigation of risk is vital for ENT departments worldwide. This article presents a systematic review of the literature examining articles which consider either the quantification of risk or strategies to mitigate risk specifically in the setting of rhinological surgery.

Design: Systematic literature review.

Results: The literature search yielded a total of 3406 returns with 24 articles meeting eligibility criteria. A narrative synthesis stratified results into two broad themes: (1) those which made an assessment as to the aerosolisation of droplets during sinus surgery, further sub-divided into work which considered macroscopically visible droplets and that which considered smaller particles; (2) and those studies which examined the mitigation of this risk.

Conclusion: Studies considering the aerosolisation of both droplets and smaller particles suggest endonasal surgery carries significant risk. While results both highlight a range of innovative adjunctive strategies and support suction as an important intervention to reduce aerosolisation, appropriate use of personal protective equipment (PPE) should be considered mandatory for all healthcare professionals involved in rhinological surgery. Studies have demonstrated that close adherence to PPE use is effective in preventing COVID-19 infection.

KEYWORDS
anterior skull base, COVID-19, endoscopic sinus surgery, rhinology, systematic review

1 | INTRODUCTION

March 2020 marked both the first national lockdown in the United Kingdom and the declaration of a global pandemic by the World Health Organisation. As we pass the unhappy anniversary of this time, it invites us to reflect upon the inescapable changes that coronavirus has wrought upon ENT practice. A series of measures were put in place to prevent health services being overwhelmed by COVID-19, initially involving the cancellation of elective surgery across the country. While this primarily aimed to allow reallocation

of resources, specific concerns were also raised about the safety of healthcare professionals during surgical procedures.[1] Coronaviruses are around 0.125 μm in size but are frequently carried in larger respiratory droplets.[2] Transmission is primarily through spread of these droplets and this places those specialties with frequent exposure to oronasal secretions at particularly high risk. Logical reasoning suggests that instrumentation of the nasal cavity has the potential to aerosol secretions within the surgical field and so risk spread of coronavirus during rhinological surgery.

In order that important clinical services can continue, the last 12 months have seen a host of institutions attempt to both quantify the risk rhinological surgery presents and mitigate it, often through implementing creative innovations. COVID-19 is truly a global pandemic and ENT departments worldwide are all the in same position of needing to continue with emergent and, where possible, elective work in a safe manner. This article presents a systematic review of the literature examining articles considering either the quantification of risk or strategies to mitigate risk in the setting of rhinological surgery.

Key points

- Endonasal surgery performed using either cold steel or powered instrumentation is an aerosol-generating procedure, with both macroscopically visible droplets and particles smaller than 10 μm detected outside the nasal cavity during simulated surgery.
- Studies suggest that combining preoperative patient screening and PPE use is successful in mitigating risk of infection.
- Suction, and in particular the introduction of additional suction devices, has been demonstrated to reduce aerosolisation during simulated rhinological surgery.
- Though a number of innovative adjunctive strategies have been proposed for mitigating risk, there is limited data to support their widespread adoption over other methods.
- No study has considered the viability of COVID-19 virus within droplets aerosolised from the nasal cavity which represents a notable limitation on published work to date.

2 | METHODS

2.1 | Ethical considerations

This was a systematic literature review. No patients or volunteers were involved and therefore formal ethics committee approval was not sought.

2.2 | Search strategy

This review was performed in keeping with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidance.[3] Under institutional licencing agreement, the Ovid (Wolters Kluwer N.V.) portal was used to search the MEDLINE database (U.S. National Library of Medicine) between 1 December 2020 and 4 March 2021. Search terms used were 'covid-19' OR 'SARS-CoV-2' AND 'sinus surgery' OR 'endonasal' OR 'transnasal' OR 'rhinology' OR 'skull base' OR 'nasal surgery'. Results were restricted to those in the English language.

All studies relating to either the assessment or mitigation of aerosolisation risk, in the setting of rhinological surgery in COVID-19 were included. It was stipulated studies that either provide some form of empirical data or propose a specific novel intervention. Both clinical and simulation studies were included. Opinion and editorial pieces were excluded.

In this review, the term 'aerosol' is used to refer to both droplets and smaller airborne particles (<10 μm), though they are referenced separately where possible.

Database searches were performed and screened by both authors with discrepancies resolved through discussion. Reference lists of included papers were scrutinised for further studies. The heterogeneous nature of the studies included precluded meta-analysis and so a qualitative synthesis was chosen to present the results. Where possible, risk of bias assessment was performed using ROBINS-I (Risk of Bias In Nonrandomised Studies) criteria.[4] Studies were also graded as to their level of evidence using the Oxford Centre for Evidence-Based Medicine criteria.[5]

3 | RESULTS

The literature search yielded 3406 returns. The PRISMA flow chart can be found in Figure 1. With duplicates removed, 3305 were screened based on both titles and abstracts. In keeping with the above criteria, 3275 articles were excluded based on lack of relevance. Twenty-nine full-text articles were scrutinised for eligibility. Six were excluded: two review articles[6,7] and four editorial/opinion pieces.[8-11] One further study was identified from analysis of reference lists,[12] resulting in a total of 24 articles meeting eligibility criteria.

Given the heterogeneity of the studies (Table 1), results were stratified into two broad themes: (1) aerosolisation of droplets during endonasal surgery, further subdivided into those which consider macroscopically visible droplets (1.1) and those which consider smaller particles (1.2), and (2) mitigation of risk.

3.1 | Aerosolisation of droplet during sinus surgery

3.1.1 | *Macroscopically visible droplets*

Macroscopically visible droplet spread was assessed in six studies, all of which used florescent tracers to map droplet spread.[13-18]

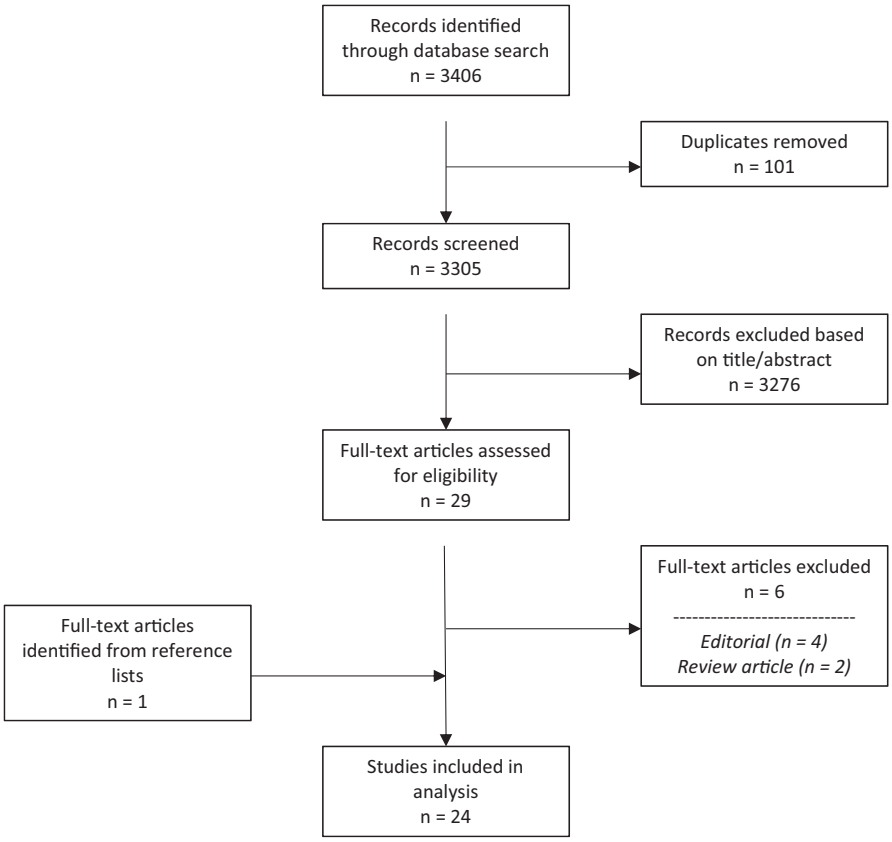

FIGURE 1 PRISMA flow diagram

All of these studies demonstrated that use of a high-speed drill aerosolised droplets outside of the nasal cavity.[13-18] No detectable droplet spread was detected in two studies considering use of non-powered 'cold' instrumentation,[13,14] and one assessing utilisation of an ultrasonic aspirator (UST-2001; Stryker Co., USA).[14]

Both Sharma et al.[14] and Leong et al.[15] found that microdebrider had the propensity to generate extranasal droplets seen on examination under UV light. Contradictory results were found by other groups though with Workman et al.[13] and Jones et al.,[16] working on cadaveric experimental settings, noting that microdebrider application to nasal mucosa did not produce detectable droplets.

3.1.2 | *Smaller particles*

The aerosolisation of smaller particles (≤10 μm) was considered in six studies.[19-24] An optical particle counter (OPC) was used,[19-23] permitting detection of such particles and assessing their number, concentration and size. Using an OPC capable of detecting particles 1.0–10.0 μm (OPS 3330; TSI Inc., USA), Workman et al.[19] analysed aerosolisation following cold steel instrumentation, electrocautery and use of the microdebrider and high-speed drill in a cadaveric setting. Readings were taken with 30 second periods of activity. Significant particles were detected following electrocautery and high-speed drill application to the sphenoid rostrum but no particles were detected with either cold steel instrumentation or microdebrider use. A further study from the same group also detected particles <10 μm in size following endonasal high-speed drill use.[20]

Later work by Sharma et al.[21] also utilised an OPC (OPS 3330; TSI Inc.) but considered even smaller particles, ranging 0.3–10 μm. In a similar cadaveric study to that of Workman et al.[19] above, they performed cold steel instrumentation, electrocautery and tested use of the microdebrider, high-speed drill and ultrasonic aspirator. In contrast, they found that all procedures produced significant increases in particles <10 μm compared to baseline, noting that most particles were <1 μm, explaining the disparity between their work and that of Workman et al.[19] Sharma et al.[21] also showed significant differences in particle detection between procedures, with the use of the high-speed drill generating the most and powered endoscopic sinus surgery simulations the least. That the use of the microdebrider during these simulations generated lower levels of aerosols than cold instrumentation could also be linked to the role of suction within the microdebrider device.

Although OPC technology allows quantification of particles <10 μm, it does not consider their aerodynamic properties. The use of a cascade impactor allows for not only particle detection but also an assessment as to their momentum, based on density and speed. Such results are arguably more useful in measuring risk of aerosolisation than those captured by OPC alone and, based on this, Dharmarajan et al.[24] performed cadaveric simulations with cascade impactor (Next Generation Impactor; Copley Scientific, UK) and fluorescent tracer. In keeping with similar works, they demonstrated production of particles <3.30 μm after endonasal drilling but, using riboflavin as a tracer, were able to filter results to confirm that particles detected were fluorescent and so from the drilled surface.

TABLE 1 Summary table for all studies included in review

Author(s) (year) Journal Country	Setting	Risk analysis	Mitigation strategies	Results	Level of evidence Risk of bias
Risk analysis					
Murr et al.[22] *Am Journal Rhinol Allergy*USA	Prospective, observational cohort study $n = 5$	Measurement of aerosol concentration with optical particle sizer following use of cold instrumentation, microdebrider and drill	None	Use of microdebrider and drill exposed surgeon to higher levels of aerosols than use of cold instrumentation (both $p = 0.001$) No significant difference between microdebrider and drill ($p = 0.59$)	Level 4 (case-control study) Risk of bias: Low
Sim et al.[17] *Ann Otol Rhinol Laryngol*USA	Experimental cadaveric simulation	Measurement of vitamin B2 and fluorescein with both UV blacklight and cascade impactor following nebulisation and use of drill	None	Vitamin B2 proposed as superior to fluorescein as fluorescent tracer for particles ≤3.30 μm Particles ≤3.30 μm measured after endonasal drill use	Level 4 (case series) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Workman et al.[13] *Int Forum Allergy Rhinol*USA	Experimental cadaveric simulation	Measurement of fluorescein with a blue-light filter and digital image processing following use of cold steel instrumentation, microdebrider and drill	None (N95 and VENT-N-95 masks considered in setting of outpatient endoscopy, not in surgical simulation, so not considered further)	Cold instrumentation and microdebrider use did not generate detectable aerosols Significant aerosolisation was detected with use of drill	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Workman et al.[19] *Otolaryngol Head Neck Surg*USA	Experimental cadaveric simulation	Measurement of aerosol concentration with optical particle sizer following use of cold steel instrumentation, electrocautery, microdebrider and drill	None (N95 and VENT-N-95 masks considered in setting of outpatient endoscopy, not in surgical simulation, so not considered further)	Cold steel instrumentation and microdebrider use did not produce measurable particles Particles 1–10.0 μm measured with use of electrocautery and drill	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Sharma et al.[23] *Laryngoscope Investig Otolaryngol*USA	Prospective, observational cohort study $n = 9$ (septoplasty $n = 3$, sinus surgery $n = 3$, anterior skull base surgery $n = 3$)	Measurement of aerosol concentration with optical particle sizer during septoplasty, endoscopic sinus surgery and skull base surgery with use of cold steel instrumentation, microdebrider, drill and coblator	None (standard surgical mask and VENT-N-95 masks considered in setting of outpatient endoscopy, not in surgical simulation, so not considered further)	No detectable spikes in aerosolisation during septoplasty Detectable particles produced during sinus surgery (including during cold instrumentation) and skull base surgery (with electrocautery and coblation but not with drill use)	Level 4 (case-control study) Risk of bias: Low

(Continues)

TABLE 1 (Continued)

Author(s) (year) Journal Country	Setting	Risk analysis	Mitigation strategies	Results	Level of evidence Risk of bias
Patient testing and PPE use					
Naik et al.[25] *J Laryngol Otol*UK	Retrospective, observational cohort study *n* = 24	None	Pre-operative patient COVID-19 testing and 14 day self-isolation PPE (level 3 FFP) for staff	No evidence of symptomatic COVID-19 infection amongst patients at 14 days postoperatively	Level 4 (case series) Risk of bias: Moderate (no patient testing; did not report on infections in staff)
Penner et al.[12] *J Endocrinol Invest*Italy	Observational cohort study *n* = 5	None	Pre-operative patient COVID-19 testing PPE (level 3 FFP) for staff Surgery restricted to cold instrumentation	No evidence of COVID-19 infection among staff on testing No evidence of symptomatic COVID-19 infection among patients	Level 4 (case series) Risk of bias: Moderate (no patient testing)
Taha et al.[27] *Am Journal Rhinol Allergy*USA	Prospective, observational cohort study *n* = 152	None	PPE (p100 respiratory filters) for staff	No evidence of COVID-19 infection amongst staff on testing	Level 4 (case series) Risk of bias: Moderate (did not report on infections in patients)
CRANIAL Consortium[26] *World Neurosurg*UK	Multicentre, prospective, observational cohort study at 12 sites *n* = 124	None	Pre-operative patient COVID-19 testing PPE (level 3 FFP) for staff	No evidence of symptomatic COVID-19 infection among patients or staff at 30 days postoperatively	Level 4 (case series) Risk of bias: Moderate (variable levels of intervention; not all patients tested; did not report on infections in staff)
Role of suction					
Sharma et al.[14] *Otolaryngol Head Neck Surg*USA	Experimental cadaveric simulation	Fluorescein droplet dispersal measured on grids following use of cold steel instrumentation, microdebrider, drill and ultrasonic aspirator	Concurrent suctioning	Droplet spread was noted with use of microdebrider and high speed drill but was eliminated with use of suction	Level 4 (case-control series) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Workman et al.[20] *Int Forum Allergy Rhinol*USA	Experimental cadaveric simulation	Measurement of aerosol concentration with optical particle sizer following use of drill and electrocautery	Nasopharyngeal placed suction tubing	Particles 1–10 μm measured after endonasal drill use and electrocautery Use of nasopharyngeal placed suction lead to significant change in detection ($p < 0.001$) comparable to baseline levels	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)

(Continues)

TABLE 1 (Continued)

Author(s) (year) Journal Country	Setting	Risk analysis	Mitigation strategies	Results	Level of evidence Risk of bias
Dharmarajan et al.[24] *Otolaryngol Head Neck Surg*USA	Experimental simulation with both cadaveric specimens and 3D printed models	Measurement of vitamin B2 as a fluorescent tracer with cascade impactor following use of drill	SPIWay nasal sheaths Flexible suction within the anterior nasal cavity	Particles ≤3.30 μm measured after endonasal drill use Use of a flexible suction inside the naris eliminated detectable aerosols	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Leong et al.[15] *Clin Otol*UK	Experimental simulation with 3D printed model and fluorescein soaked grapes and porcine ribs	Fluorescein droplet dispersal measured on grids following use of microdebrider and drill	Use of variable suction and microdebrider settings	Configuration of both suction pressure and microdebrider setting can prevent detection of extranasal droplet spread High speed drilling within the nasal cavity results in detectable droplet spread outside the nasal cavity despite use of suction	Level 4 (case-control study) Risk of bias: Moderate (laboratory setting with simulation methods which may not accurately represent *en vivo* dynamics)
Sharma et al.[21] *Otolaryngol Head Neck Surg*USA	Experimental cadaveric simulation	Measurement of aerosol concentration with optical particle sizer following use of electrocautery, microdebrider, drill and ultrasonic aspirator	Concurrent nasal suctioning	Particles 0.3–10.0 μm measured in all endonasal procedures considered Suction significantly decreases particle detection with use of rigid suction and surgical smoke evacuation system most effective	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Use of specific patient mask					
Helman et al.[18] *Oper Neurosurg*USA	Experimental cadaveric simulation	Fluorescein droplet dispersal with use of drill	3D printed mask permitting laparoscopic port for instrumentation	Droplet dispersal reduced by 86% with use of mask	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)
Viera-Artiles et al.(2020)[28] *Eur Arch Otorhinolaryngol*Spain	Experimental simulation with SIMONT rubber head model and fluorescein tracer	Fluorescein droplet dispersal measured and mapped following use of drill	3D printed 'Maskpirator'	Droplet spread reduced, though not prevented, with use of suction and 'Maskpirator'	Level 4 (case-control study) Risk of bias: Moderate (laboratory setting with simulation methods which may not accurately represent *en vivo* dynamics)
Jones et al.[16] *Laryngoscope*UK	Experimental cadaveric simulation with smoke from wood chips and fluorescein tracer	Fluorescein droplet dispersal measured and mapped using software following use of microdebrider and drill	Negative pressure mask	No droplets noted with or without mask use with use of microdebrider Droplets produced following use of drill but not with concurrent use of negative pressure mask	Level 4 (case-control study) Risk of bias: Moderate (cadaveric simulation may not accurately represent *en vivo* dynamics)

(Continues)

TABLE 1 (Continued)

Author(s) (year) Journal Country	Setting	Risk analysis	Mitigation strategies	Results	Level of evidence Risk of bias
Use of specific drape					
D'Amico et al.[30] *World Neurosurg*USA	Feasibility study	None	Patient draped in clear polyethylene sheet with apertures cut around nares	No data reported	Level 5 (expert opinion based on first principles) Risk of bias: n/a
Maharaj[31] *Eur Arch Otorhinolaryngol*South Africa	Feasibility study	None	Procedure carried out with surgeon's hands and instruments beneath a clear polyethylene sheet connected to low flow suction device	No data reported	Level 5 (expert opinion based on first principles) Risk of bias: n/a
Solari et al.[32] *Acta Neurochir*Italy	Feasibility study	None	Non-latex glove used to drape nose with apertures cut around nares Povidone Iodine used topically to prepare patient	No data reported	Level 5 (expert opinion based on first principles) Risk of bias: n/a
Tsagkovits et al.[33] *Eur Arch Otorhinolaryngol*UK	Feasibility study	None	Procedure carried out with surgeon's hands and instruments beneath a clear polyethylene sheet	No data reported	Level 5 (expert opinion based on first principles) Risk of bias: n/a
Ioannidis et al.[34] *J Laryngol Otol*UK	Experimental simulation with plastic manikin and smoke generator	Smoke generator for aerosolisation Air particle counter for particle detection	Procedure carried out with surgeon's hands and instruments beneath a clear polyethylene sheet connected to suction device	A reduction in particles of 0.3 and 0.5 μm towards baseline levels with use of drape and suction device	Level 4 (case-control study) Risk of bias: Moderate (laboratory setting with simulation methods which may not accurately represent *en vivo* dynamics)
David et al.[35] *Head Neck*USA	Retrospective, observational cohort study $n = 4$	Fluorescein droplet dispersal analysed with black light following powered endonasal procedures	Negative pressure viral isolation drape (polyethylene sheet and smoke evacuator suction tubing)	Droplets noted outside of drape system in 2 of 4 cases	Level 4 (case series) Risk of bias: Moderate (limited reporting of aerosolisation detection)

(Continues)

TABLE 1 (Continued)

Author(s) (year) Journal Country	Setting	Risk analysis	Mitigation strategies	Results	Level of evidence Risk of bias
Arefin et al.[29] *Indian J Otolaryngol Head Neck Surg* Bangladesh	Feasibility study	None	Procedure carried out with surgeon's hands and instruments beneath a clear polyethylene sheet Povidone Iodine used as nasal spray and mouthwash by staff and patients	No COVID-19 infections in 12 healthcare workers over 5-month period	Level 4 (case series) Risk of bias: Moderate (data on staff infections not robust; infections in patients not reported)

Moving from simulation studies to those with patients, Murr et al.[22] analysed particle detection during five endonasal procedures taking serial OPC readings at the position of the surgeon, scrub practitioner and anaesthetist. Significant increases in particles 0.3–10 μm were measured with microdebrider and drill use but not for cold instrumentation. Sharma et al.[23] analysed nine endonasal surgeries and mapped to a log of intraoperative steps, with specific attention to use of the microdebrider, drill and coblator. Results showed spikes in particles between 0.3 and 10 μm during sinus surgery (including during cold instrumentation) and skull base surgery (during electrocautery and coblation). Results failed to show detectable spikes during high-speed drill use, contrasting with all other studies considering this activity. The reasons for this remain unclear but could reflect limitations in sample size, given such clinical work to date has been small in scale and experimental studies, though more numerous, also remain limited in the number of simulations performed.

3.2 | Mitigation of risk

Nineteen studies considered techniques to mitigate this risk and they will be considered in terms of those which employ 'standard' precautions, those which investigate the role of suction on aerosolisation and those which report novel adjunctive techniques.[12,14-16,18,20,21,24-35]

3.2.1 | *Standard precautions*

Four studies report their experience of endonasal surgery during COVID-19 with cumulative patient number of 305.[12,25-27] Risk is mitigated through a combination of pre-operative patient testing (with or without detail of subsequent self-isolation for patients) and staff PPE use in the operating theatre, with no added precautions unique to endonasal surgery. Though there were subtle differences between each, all can be considered to reflect variation in the standard operating procedure between institutions. None make specific measurements as to aerosolisation but patient and/or staff infection levels are reported as an outcome of risk mitigation. Naik et al.[25] and the work from the CRANIAL Consortium[26] report no symptomatic COVID-19 infections in patients at 14 and 30 days postoperatively, though no formal testing was performed. Penner et al.[12] and Taha et al.[27] tested staff and found no evidence of COVID-19 infection during their case series. Taken as a whole, results suggest that preoperative patient screening, to ensure patients are COVID-19-negative, and PPE use is successful in mitigating risk, though limitations apparent in these case series include lack of description as to local level of endemic infection and so relative risk at each institution, consistency in testing of patients and staff across studies and possible unreported asymptomatic infections.

3.2.2 | *Role of suction*

The potential mitigation effects of suction during endonasal surgery were evaluated in five studies.[14,15,20,21,24] Two studies considered the role of suction in mitigating spread of droplets. Sharma et al.[14] noted that the introduction of a third hand for concurrent suction completely eliminated detection of fluorescein-soaked droplets following use of both microdebrider and endonasal drill. Leong et al.[15] also observed that suction during microdebrider use eliminated droplet spread, achieved through use of the inbuilt suction alone (without an additional device) provided microdebrider hand-piece settings were set at 13 *g* oscillation, 25 ml/min irrigation and 200 mmHg suction pressure. The results of Leong et al.[15] differed from those of Sharma et al.[14] in their finding of ongoing droplet spread despite the addition of a second suction device during high-speed drill use. This could be explained by methodological differences however as though the drilling simulations in the Sharma et al.[21] study were run for a longer duration than those by Leong et al.[15] (being 3 min rather than one minute of powered instrumentation, respectively), the concentration of fluorescent tracer used in their cadaveric work was much lower (1mg/mL of fluorescein vs. 40mg/mL).

Workman et al.,[20] Dharmarajan et al.[24] and Sharma et al.[21] examined the role of suction in mitigating the spread of smaller particles ≤10 μm in size. Workman et al.[20] noted a reduction in the detection of particles 1–10 μm down to baseline levels, with use of a third-hand delivering nasopharyngeal suction, during simulated high-speed drilling of both the sphenoid rostrum and medial maxillary wall for 5-min periods. Dharmarajan et al.[24] also found that in 2-min simulations of drilling of the sphenoid rostrum, detection of particles ≤3.3 μm were eliminated through use of an additional third-hand suction device, irrespective of whether it was positioned within the nasopharynx or just inside the nasal cavity. As has been discussed above, the work of Sharma et al.[21] considered a greater range of particles 0.3–10 μm. They also noted the significant impact of adding in concurrent rigid suction with marked reduction in particle detection following simulations of sphenoid drilling, electrocautery and use of the ultrasonic aspirator but, perhaps in keeping with the greater sensitivity of the OPC they utilised, their study did reveal that aerosolisation was ongoing despite the reductions described. Sharma et al.[21] delved further into the impact of suction, comparing the impact of concurrent endonasal suction with both the construction of a suction ring surrounding the nares and a surgical smoke evacuation system, mounted over the patient's mouth. They noted the surgical smoke evacuation system to be the most superior device, recommending its use alongside concurrent nasal rigid suction to mitigate risk further.

3.2.3 | *Adjunctive techniques*

Other groups have considered more novel applications to mitigate risk. Three studies tested the fitment of a specific mask on the patient.[16,18,28] All such work was performed in simulated settings and considered droplet spread in terms of splatter evaluated through fluorescent tracing with fluorescein. Viera-Artiles et al.[28] and Helman et al.[18] used 3-D printed mask designs and evaluated droplet dispersal following endonasal high-speed drill use. While both studies noted a reduction in droplet detection, neither prevented droplet aerosolisation completely. Jones et al.[16] added suction beneath their patient mask to create a negative pressure environment finding that droplet spread was eliminated during cadaveric sinus surgery simulations, using both the microdebrider and high-speed drill. Though encouraging, this work does not consider aerosolisation of smaller particles.

Five very similar feasibility studies report on their experience of specific patient draping.[29-33] The majority employ a polythene sheet, under which the surgeon operates.[29-32] Of these, only Arefin et al.[29] published outcomes, reporting no COVID-19 infections among 12 theatre team members over a 5-month period. Both Ioannidis et al.[34] and David et al.[35] also draped the patient in a polyethylene sheet but, in a similar strategy to Jones et al.[16] above, attached suction to create a negative pressure environment. Ioannidis et al.[34] considered the aerosolisation of small particles, simulated with a smoke generator in a plastic manikin. An OPC (Fluke 985; Fluke Co., USA) was used to measure particles 0.3–0.5 μm which were still detected outside of their drape system, albeit at reduced levels. Similarly, David et al.[35] found that fluorescein droplets continued to be noted outside of their draping in two of four patients evaluated.

4 | DISCUSSION

4.1 | Synopsis of key/new findings

Studies considering the aerosolisation of both droplets and smaller particles suggest endonasal surgery carries significant risk.[13-24] Endonasal surgery performed using either cold steel or powered instrumentation has the propensity to be aerosol generating with both macroscopically visible droplets and particles <10μm detected outside the nasal cavity during simulated surgery.[13-24]

4.2 | Clinical applicability of this review

Though risk of transmission will be dependent on factors such as local infection rate, testing and vaccination status, it has been demonstrated that close adherence to PPE use, particularly with use of FFP3 level masks, is effective at preventing COVID-19 infection for healthcare professionals involved in endonasal rhinological and skull base surgery.[12,25-27]

While studies have considered a wide range of different endonasal procedures, high-speed drill use emerged most consistently as having the potential to be aerosol generating.[13-22,24] Unfortunately, heterogeneity in terms of study design prevents accurate conclusions being drawn to allow recommendations regarding site and duration of drill use. It is intriguing to note that the single clinical study

utilising an OPC for particle detection found no increase in detectable particles following endonasal drilling.[23] Such findings should be interpreted with caution, however, given the small sample size involved in this study and that they remain at odds with the majority of other work considering high-speed drill use.[13-22,24]

Results propose suction as an important variable to reduce aerosolisation.[14,15,20,21,24] Accordingly, surgeons should consider introducing a second suction device via a three-hand technique. When using devices with in-built suction capabilities, surgeons must be aware of techniques to unblock instruments safely and to prevent blockage (e.g. adequate irrigation, reducing oscillations to allow suction to work). Furthermore, there is evidence to suggest that a greater understanding of both the design and functionality of instruments used during rhinological surgery can also be beneficial to not only optimise operational capability but also reduce aerosolisation of fluid from the surgical field.

The addition of a variety of adjunctive techniques (e.g. drapes,[29-35] negative-pressure masks.[1618,28]) reflect the ingenuity of clinical groups across the world. Though innovative, such ideas would benefit from extended real-life testing and should also be balanced with their practicality and cost given that results suggest they do not eliminate aerosolisation to the point where staff would not wear higher levels of PPE.

4.3 | Areas for future research

While there is an obvious need for larger scale clinical studies to attempt to support some of the more tentative findings reviewed here, there are some specific avenues in which future work could be focussed. Although OPC technology has allowed studies to test for particles as small as 0.3μm, some reports place COVID-19 at 0.1μm in diameter.[2] Ideally work should employ methods of detecting particles of this size to prevent underestimation when assessing risk.

Ultimately, while there are a host of studies considering the spread of both droplets,[13-18] through which COVID-19 has been reported to spread, and smaller particles,[19-24] of which COVID-19 is one, all work has been somewhat indirect in its methodology with no studies able to ascertain whether COVID-19 would be found in any of the aerosols detected or, and somewhat crucially, whether it would be viable to cause infection in another host. Indeed, there have been recent reports suggesting that plume generated from electrocautery is unlikely to contain viable virus particles.[36] While it is challenging to prescribe the best means by which to achieve these aims, harnessing existing methods for sampling airborne viruses may provide more definitive answers.[37]

4.4 | Limitations of this review

As with all systematic reviews, the search strategy employed was broad and it is expected that some studies may have been missed. While the reference lists of included studies were scoured for further publications meeting the inclusion criteria, a search across multiple databases could have yielded studies overlooked in this work. The search strategy was also limited to those published in English. Readers should exercise caution that the studies reviewed here represent a single point of time and the findings of future work could alter the conclusions drawn here.

Finally, it could be posited that studies considering either the assessment of aerosolisation or mitigation of risk in literature from other specialties (e.g. Anaesthetics) or from other research sectors (e.g. Engineering) could be transferable to rhinological practice. Whilst it could be logically reasoned that findings from such work may be extrapolated to rhinology surgery, this would have involved a series of assumptions and would significantly limit the strength of any conclusions which could be drawn when results are applied in a different and untested context.

5 | CONCLUSION

Though largely confined to simulated settings, the current body of evidence suggests that routine rhinological practice has the capacity to create significant aerosolisation of both droplets and smaller particles.[13-24] While several studies suggest this can be mitigated to a degree, primarily through use of suction,[14,15,20,21,24] it is challenging to recommend specific mitigation strategies that will eliminate risk completely, particularly with use of the high-speed drill. Studies do indicate that close adherence to standard operating procedures,[12,25-27] concerning both pre-operative patient testing and intraoperative PPE use for staff, can be effective at preventing spread of COVID-19 during rhinological surgery.

CONFLICT OF INTEREST

The authors (SPW and SCL) have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS

SPW and SCL designed the work; SPW and SCL acquired and analysed data; SPW and SCL drafted, revised and approved the manuscript; SPW and SCL agree to be accountable for all aspects of the work.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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