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REVIEW

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Airborne transmission of SARS-CoV-2 via aerosols

Laura Comber[1] | Eamon O Murchu[1] | Linda Drummond[1] | Paul G. Carty[1] | Kieran A. Walsh[1] | Cillian F. De Gascun[2] | Máire A. Connolly[3] | Susan M. Smith[4] | Michelle O'Neill[1] | Máirín Ryan[1,5] | Patricia Harrington[1]

[1]Health Technology Assessment Directorate, Health Information and Quality Authority, Dublin, Ireland

[2]National Virus Reference Laboratory, University College Dublin, Dublin, Ireland

[3]School of Medicine, National University of Ireland Galway, Galway, Ireland

[4]Department of General Practice, Health Research Board Centre for Primary Care Research, Royal College of Surgeons in Ireland, Dublin, Ireland

[5]Department of Pharmacology & Therapeutics, Trinity College Dublin, Dublin, Ireland

Correspondence

Laura Comber, Health Information and Quality Authority, Dublin, Ireland.
Email: lcomber@hiqa.ie

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Summary

A key consideration in the Covid-19 pandemic is the dominant modes of transmission of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus. The objective of this review was to synthesise the evidence for the potential airborne transmission of SARS-CoV-2 via aerosols. Systematic literature searches were conducted in PubMed, Embase, Europe PMC and National Health Service UK evidence up to 27 July 2020. A protocol was published and Cochrane guidance for rapid review methodology was adhered to throughout. Twenty-eight studies were identified. Seven out of eight epidemiological studies suggest aerosol transmission may occur, with enclosed environments and poor ventilation noted as possible contextual factors. Ten of the 16 air sampling studies detected SARS-CoV-2 ribonucleic acid; however, only three of these studies attempted to culture the virus with one being successful in a limited number of samples. Two of four virological studies using artificially generated aerosols indicated that SARS-CoV-2 is viable in aerosols. The results of this review indicate there is inconclusive evidence regarding the viability and infectivity of SARS-CoV-2 in aerosols. Epidemiological studies suggest possible transmission, with contextual factors noted. Viral particles have been detected in air sampling studies with some evidence of clinical infectivity, and virological studies indicate these particles may represent live virus, adding further plausibility. However, there is uncertainty as to the nature and impact of aerosol transmission of SARS-CoV-2, and its relative contribution to the Covid-19 pandemic compared with other modes of transmission.

KEYWORDS

aerosols, coronavirus, Covid-19, infection control, review, SARS-CoV-2, transmission

Abbreviations: AGP, aerosol generating procedure; NHS, National Health Service UK; PPE, personal protective equipment; RNA, ribonucleic acid; rRT-PCR, real-time reverse transcription polymerase chain reaction; RT-PCR, reverse transcription polymerase chain reaction; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; WHO, World Health Organization.

Máirín Ryan and Patricia Harrington are co-senior authors.

1 | INTRODUCTION

An important consideration in the Covid-19 pandemic is the dominant modes of transmission of the SARS-CoV-2 virus. Transmission of respiratory viruses is typically through three modes as follows: contact, droplet and or aerosol.[1–3] Contact transmission can be direct, such as on an infected individual's hands, or indirect through the presence of virus particles on intermediate objects known as fomites.[2,3] Droplet transmission occurs with exposure to large infectious respiratory particles containing viral material from a symptomatic individual who has respiratory symptoms (e.g., coughing or sneezing) or who is talking or singing. In these circumstances, virus containing respiratory droplets can reach the mouth, nose or eyes of a susceptible person and can result in infection. This mode of transmission typically requires close contact as the particle size denotes a relatively limited travel distance before settling to the ground or surrounding surfaces.[1,3] Airborne transmission is defined as the spread of an infectious agent caused by the dissemination of aerosols (droplet nuclei).[3] Such transmission is distinct from droplet as it is based on a smaller particle size, enabling a greater travel distance and the potential to remain suspended in air for prolonged periods.[2,3] Aerosols are emitted to varying degrees and sizes depending on the activity in question such as breathing, talking, singing and residually following coughing or sneezing.[1] The World Health Organization (WHO) defines aerosols as particles ≤5 microns in diameter[3]; however, a defined cut-off has been highlighted as somewhat ambiguous with little definitive support.[1]

Irrespective of the particle size definition, the principal differentiation of airborne from droplet transmission is the infection risk of aerosols through airborne contamination. This has important implications for public health decision-making for the general population and healthcare workers.[1,2] The risk of airborne transmission, and the virulence of the respective pathogen, are important considerations that inform infection prevention and control measures including the requirement for, and type of personal protective equipment (PPE) that should be worn by healthcare workers, and the use of face coverings by the general population.[4,5] For instance, measles is a highly infectious respiratory agent, which can transmit via aerosols and requires the implementation of strict airborne precautions and use of sophisticated PPE.[6] The determination of the risk of a respiratory pathogen to transmit via aerosols, and the associated virulence, is particularly important in the context of pandemic settings such as Covid-19 where preservation of PPE supplies and a balanced risk assessment are crucial.[4,7]

The aim of this rapid review is to synthesise the available evidence for airborne transmission of SARS-CoV-2 via aerosols.

2 | METHODS

A rapid review was conducted following a standardised protocol in keeping with the Cochrane Rapid Review methodology.[8]

2.1 | Data sources and searches

Electronic searches were conducted in PubMed, Embase, Europe PubMed Central and National Health Service UK evidence. The search terms and detailed search strategy are provided in Table S2. Searches were conducted from 1 January 2020 up to, and including, 27 July 2020.

2.2 | Study selection

Studies were eligible for inclusion if they included reverse transcription polymerase chain reaction (RT-PCR) confirmed SARS-CoV-2 ribonucleic acid (RNA) detection or detection of viable virus using culturing methods; including observational studies, epidemiological investigations, laboratory studies and environmental studies. Animal studies and studies where the likely route of aerosol transmission was not explicitly deduced by the authors were excluded.

2.3 | Data extraction and quality assessment

A data extraction form was developed for this review. One reviewer extracted data using the data extraction form which was then cross-checked by a second reviewer, with discussions held between the reviewers where discrepancies were identified.

For the quality appraisal of case series, no universally accepted quality appraisal tool was identified; therefore a de-novo tool based on existing tools was developed as outlined in the protocol associated with this review.[8] A formal quality appraisal tool was not identified for air sampling or virological studies, however these studies were informally appraised to identify any potential methodological limitations.

3 | RESULTS

As shown in the PRISMA flow diagram in Figure 1, the collective search resulted in 3,308 citations; following removal of duplicates, 2,998 citations were screened for relevance, with 133 full-texts assessed for eligibility. Twenty-eight studies were identified for inclusion in this review.[9–36] Eight studies represented epidemiological case series of SARS-CoV-2 clusters or outbreaks (with one including a mechanistic analysis),[9,12,13,21,28,31–33] 16 were air sampling studies,[10,11,14–17,19–21,23,24,29,30,34–36] and four were virological studies.[18,25–27] A summary of the included studies is provided in Table S1. The results of this review are presented and summarised by study design.

3.1 | Epidemiological studies

Eight studies were epidemiological case series assessing outbreaks or clusters of SARS-CoV-2 infection,[9,12,13,21,28,31–33] with one including

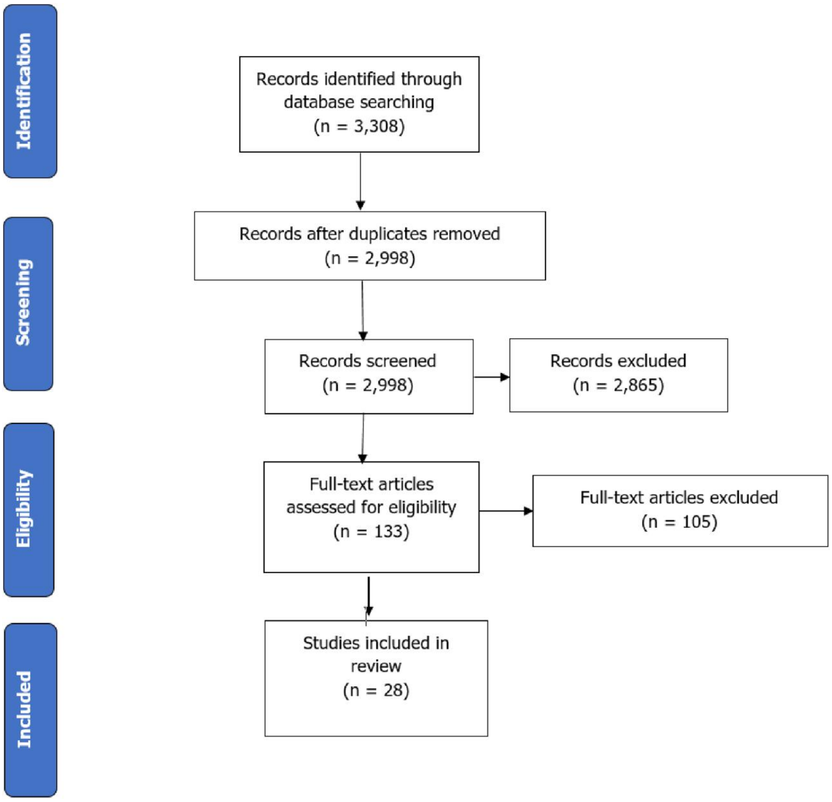

FIGURE 1 PRISMA flow diagram

a mechanistic element through onsite experiment and computer simulation.[13] Three studies related to cases in China,[9,13,28] two to cases in the United States,[12,32] one to an outbreak in Germany,[33] one to the Diamond Princess cruise ship,[31] and one included a combined analysis of data from China, the United States and Italy.[21]

Cai et al.[9] analysed a cluster of infections related to a shopping mall in Wenzhou, China. The index case was presumed to be an asymptomatic carrier with travel association to Wuhan, China. In total, Covid-19 was diagnosed in seven employees in the same office as the index case, seven mall staff from three separate floors and 10 mall customers, alongside a number of outside contacts. The authors conclude that low intensity transmission appears to have occurred without prolonged close contact; that is, the virus spread by indirect transmission perhaps resulting from virus contamination of common objects, by virus aerosolisation in a confined space, or spread from asymptomatic infected persons.

Günther et al.[33] analysed a cluster of SARS-CoV-2 infections related to a shift of employees at a German meat processing plant. The index case, based on sequencing and bioinformatics analyses of infections, was an asymptomatic employee who had contact with a known case from another plant where an outbreak had occurred. Excluding the index case, 29 (20.7%) of 140 employees who had worked on the same shift over three consecutive days tested positive for SARS-CoV-2 with RT-PCR. The authors highlighted that although secondary infections could have occurred through close contact, the contextual layout of the plant supports the transmission of SARS-CoV-2 within an 8 m radius of the index case's work station. Furthermore, the authors speculate that environmental conditions of the plant area including air recirculation and low temperatures may have facilitated the spread.

Hamner et al.[12] reported a cluster of SARS-CoV-2 infections related to a choir practice of 61 people in Washington, United States. The presumed index case was symptomatic at the time of the event with active symptoms for 3 days prior. Excluding the index case, 52 (86.7%) of 60 attendees became ill; 32 (61.5%) of these cases were confirmed to be SARS-CoV-2 infected by RT-PCR testing and an additional 20 (38.5%) were considered to have probable infections. Of these cases, three were hospitalised and two died. From the descriptive analysis, the authors highlight that there were several opportunities for droplet and fomite transmission. In addition, the authors further suggest that the act of singing itself may have contributed to transmission through emission of aerosols.

Li et al.[13] analysed the potential contribution of aerosol transmission to a cluster of SARS-CoV-2 infections across three non-associated families dining in a restaurant in Guangzhou, China. The index case was a symptomatic individual seated at the middle table in a row of three, with confirmed cases subsequently identified from all three tables. In total, there were 10 confirmed cases of Covid-19 from the three family tables. The authors provided an epidemiological analysis alongside onsite experimental and computer simulations using ethane tracer gas measurements and computational fluid dynamics. The results of the analysis indicated highest gas concentrations (simulating aerosol emission from the index case) at the primary table and the neighbouring tables of infected cases. The concentrations were reduced at neighbouring tables where no cases were reported, and lower again at the remaining remote tables in the restaurant. The authors deduced an odds ratio of being infected with SARS-CoV-2 as being higher with higher gas concentrations. Although other forms of transmission may also have occurred, the authors conclude that their findings support the probability of an extended short-range aerosol spread having occurred in the poorly ventilated restaurant.

Shen et al.[28] analysed two outbreaks of SARS-CoV-2 infections from two distinct events in the Zhejiang province of China. The first cluster occurred on a bus of 67 passengers travelling to a worship event with a pre-symptomatic case who became symptomatic upon returning from the event. In total, 24 passengers on the bus were infected, with distribution spread throughout the bus. No statistically significant increase in risk was found with closer proximity to the index case. No passengers on a second bus were infected, suggesting transmission occurred on the index case bus rather than at the worship event itself. In the second cluster, 30 individuals attended a training workshop across a 3-day period with the index case thought to be an asymptomatic female. On the bus in cluster one and the conference rooms in cluster two, central air-conditioners were on indoor re-circulation mode. The authors concluded that in both clusters, airborne transmission at least partially explains the infection rates, suggesting that closed environments with air re-circulation may play a significant role in transmission.

Bays et al.[32] analysed nosocomial outbreaks of SARS-CoV-2 in two healthcare facilities. Both index cases were admitted without suspicion of SARS-CoV-2 and hence contact, droplet or airborne precautions were not implemented. While unclear what proportion were tested, of 421 healthcare workers who were deemed to have had exposure to the index cases, eight tested positive with RT-PCR testing. Through an analysis of electronic medical records and structured interviews with the staff, the authors determined that close contact was the likely route of transmission. The index cases both underwent aerosol generating procedures (AGPs). Although the secondary cases were also present for the AGPs performed, the authors highlight that these individuals had prolonged close contact with the index cases without adequate PPE, and given that there was no apparent transmission to staff or patients elsewhere on the wards, suggested that these findings are more consistent with transmission by respiratory droplets rather than airborne transmission.

Zhang et al.[21] analysed trends in SARS-CoV-2 infections across three locations; Wuhan, New York and Italy, with the authors claiming airborne transmission as the dominant mode. However, it must be noted that the findings of this study have been brought into wide disrepute with concerns about the analysis used and the conclusions drawn, with some calling for clarification or retraction.[37,38] The primary outcome, using a linear model of analysis, was the avoided cases of infection possibly due to the wearing of face coverings, with 78,000 fewer infections in Italy and over 66,000 fewer infections in New York City when face coverings were mandated. The authors conclude that their findings support the hypothesis that face coverings reduce aerosol transmission of SARS-CoV-2 infection.

Almilaji et al.[31] analysed the apparent contribution of cabin occupancy to infection rates aboard the Diamond Princess cruise ship during the quarantine period implemented on the ship following an outbreak of SARS-CoV-2. Of note, this study was deemed to be of particularly low quality in the context of this review. In total, 619 cases were confirmed on the cruise ship of which 163 cases were recorded as having symptom onset dates during the quarantine period; details of 115 cases were assessed by the authors. Using count data from published reports, the authors report that the symptomatic infection rate during the quarantine period in cabins with previously confirmed cases was not significantly higher than that in cabins without previously confirmed cases. The authors conclude that although other forms of transmission were not investigated and cannot be discounted, their findings suggest that airborne transmission between cabins may have played a role in the spread of SARS-CoV-2 during the quarantine period.

3.2 | Air sampling studies

Sixteen studies included air sampling for the detection of SARS-CoV-2 viral RNA.[10,11,14–17,19–21,23,24,29,30,34–36] Six of the studies were conducted in China,[11,14,15,22,30,34] three in Singapore,[16,19,24] two in the United States,[17,36] and one each in Hong Kong,[29] Iran,[10] Italy,[35] Japan[20] and the United Kingdom.[23] The studies were largely conducted in hospital settings including clinical and non-clinical areas with known Covid-19 patients in the vicinity[10,11,14–17,19,22–24,29,30,34–36]; one study was conducted on a cruise ship which had experienced an outbreak of SARS-CoV-2.[20] Thirteen studies analysed air samples from areas known to have Covid-19 cases in the vicinity, two studies included air sampling with additional analyses of exhaled breath condensate from patients, and one analysed exhaled breath condensate exclusively. Three studies attempted to culture virus from positive samples.[17,23,36]

Detection of SARS-CoV-2 RNA was reported in 12.5%–66.7% of air samples in 10 of 15 studies.[11,14,15,17,23,24,30,34–36] Guo et al.[11] reported positive detection in 14/40 (35%) air samples from an intensive care unit (ICU) including samples taken near air outlets, within patient rooms and in an office area, with detection from general wards in 2/16 (12.5%) samples which were all in close proximity to Covid-19 patients. Similarly, on sampling patient rooms with sampling devices in relatively close proximity to the patients' beds, Chia et al.[24] noted detection of SARS-CoV-2 RNA in two of three patient rooms sampled (66.7%); concentrations ranged from 1.84×10^3 to 3.38×10^3 copies per m^3 and particles identified in sizes including 1–4 μm and >4 μm. Liu et al.[14] reported positive detection in a number of samples from patient areas (range 0–19 copies m^{-3}), medical staff areas (range 0–21 copies m^{-3}), and public areas (range 0–11 copies m^{-3}). Zhou et al.[23] detected SARS-CoV-2 RNA in 14/31 (38.7%) air samples with detection from all eight areas analysed including both clinical and non-clinical areas. Of 32 samples assessed, Santarpia et al.[17] reported 63.2% of in-room and 58.3% of outside room air samples within a ward and quarantine unit were positive for the detection of SARS-CoV-2 RNA. An additional study by the same authors[36] noted detection of SARS-CoV-2 RNA in all particle sizes (<1 μm, 1–4 μm and >4.1 μm) from 18 air samples collected from the end of the patient beds in the rooms of six Covid-19 cases. Lei et al.[34] reported detection of

SARS-CoV-2 in one air sample taken within an ICU and in a further three samples taken from an isolation ward (two from a bathroom and one from the ward itself), however it was unclear how many samples were collected in total. Razzini et al.[35] noted detection of SARS-CoV-2 RNA in an ICU and in patient corridors in 20/37 (54.1%) samples. From a range of sampling sites within a hospital and hotel quarantine facility, Ma et al.[15] noted just one positive detection of SARS-CoV-2 RNA from an unventilated hotel quarantine bathroom, while Jiang et al.[30] reported one positive air sample (3.57%, 1/28) in their study with the sample taken from a ward housing an intensive care Covid-19 patient who had undergone tracheal intubation the previous day. The remaining five studies did not detect SARS-CoV-2 RNA in air samples.[10,16,19,20,22]

Three studies presented results on the detection of SARS-CoV-2 RNA in the exhaled breath condensate of confirmed cases.[15,22,29] Zhou et al.[22] noted detection in 2/9 (22%) samples collected from recovering Covid-19 patients, with at least 14 days since symptom onset. Ma et al. reported a detection rate of 5/30 (16.7%) from exhaled breath condensate samples taken from Covid-19 patients within 14 days of symptom onset. Cheng et al.[29] noted no positive detection of SARS-CoV-2 RNA in the exhaled breath of six Covid-19 patients, with and without the use of surgical masks (median of 3.5 days since symptom onset), with the authors concluding that the results indicated the airborne route was not the predominant mode of transmission.

Three studies attempted to conduct virus culturing on samples in which SARS-CoV-2 RNA was detected.[17,23,36] Zhou et al.[23] reported no successful virus cultured from the 14 positive air samples within their study. Santarpia et al.[17] highlighted that although low concentration levels of the virus in the recovered air samples resulted in unsuccessful cultivation, results for one sample indicated some evidence for the presence of replication competent virus.[17] However, an additional study from the same authors,[36] did note statistically significant viral growth (defined as rRT-PCR samples in which a significant increase in RNA was detected in the supernatant) in three of 18 positive samples, all of which were <1 micron μm particle size, while two further samples of 1–4 micron μm particle size demonstrated viral growth but did not reach statistical significance. Supplementary western blot and transmission electron microscopy analysis of these samples also showed evidence of viral proteins and intact virions in a number of cultures.

3.3 | Virological studies

Four virological studies were included in this review.[18,25–27] All were conducted in controlled laboratory conditions in the US with two studies investigating the persistence of the SARS-CoV-2 virus in aerosolised particles,[18,27] and two analysing the effect of varying environmental conditions on the viability of the virus.[25,26]

van Doremalen et al.[18] investigated the persistence of SARS-CoV-2 viability through the generation of aerosols replicating those produced by the upper and lower respiratory tract of infected humans in a controlled laboratory experiment. The authors noted the SARS-CoV-2 virus remained viable in aerosols throughout the duration of the 3-hour experiment (reduction in infectious titre from $10^{3.5}$ to $10^{2.7}$ $TCID_{50}$ per L of air) and presented a median half-life estimate of 1.1 h (95% credible interval 0.64–2.64), highlighting a plausibility for aerosol transmission of the virus. The authors noted similar viability results for SARS-CoV and SARS-CoV-2 when the two viruses were directly compared. Fears et al.[27] analysed the short- and long-term efficiency of the SARS-CoV-2 virus in aerosols. The authors noted the short-term dynamic aerosol efficiency of SARS-CoV-2 surpassed those of SARS-CoV and Middle East respiratory syndrome, while longer term analysis indicated detection of SARS-CoV-2 in aerosols at five time points of a singular experiment (up to 16 h) with minimal decreases in concentration measured in viral genome copies. Examination with electron microscopy highlighted that virus particles aged for 10 min or 16 h were similar in shape and general appearance to those examined in samples collected before aerosolisation. The authors noted that these collective results potentially indicate retained infectivity and virus integrity of SARS-CoV-2 for up to 16 h in aerosols.

In terms of the effect of environmental conditions on SARS-CoV-2 in aerosols, Schuit et al.[25] investigated the effect of varying levels of humidity and simulated sunlight on the persistence of the SARS-CoV-2 virus. Within controlled laboratory experiments, the authors noted variations in relative humidity alone did not affect the decay rate; however simulated sunlight (Ultraviolet A and Ultraviolet B levels similar to natural) inactivated the virus in aerosols in both suspension matrices tested, with half-lives of less than 6 min; 90% of the virus was inactivated in less than 20 min for all simulated sunlight levels investigated. With regards to temperature, Yu et al.[26] noted a 2.7-fold log reduction $TCID_{50}$ (estimated 99.8% viral load reduction) in SARS-CoV-2 suspended aerosols with the use of a novel nickel air filter heated to approximately 200°C.

3.4 | Study quality and quality of the evidence

The quality of evidence from the epidemiological studies was low due to the inherent biases associated with these retrospective study designs. Where applicable, the majority of studies provided sufficient detail of case descriptions, context and detection of outcome. Of the four studies employing statistical techniques two were deemed to be appropriate.[13,28] The use of linear regression in the study by Zhang et al.[21] was deemed inappropriate in the context of their analyses, with additional critique in terms of the lack of a control population and the exclusion of a lag time between infection and reported cases. Further concerns were also raised about the causative conclusions drawn given the associative nature of the analyses in this study. Additionally, the conclusions drawn from the count data analysis conducted by Almilaji et al.[31] raised considerable concerns given that only a subset of the available data was used and potential confounders were not accounted for.

The majority of air sampling studies provided a reasonable degree of information relating to the methodology employed including collection methods, timing of collection and sampling sites. The use of RT-PCR testing and choice of gene targets were typically well reported, however the thresholds for detection were inconsistent across studies and were unclear in a number of cases. Similarly, the virological studies provided a reasonable level of detail regarding the methodology employed and the conditions assessed; however, it is not possible to ascertain if the conditions in the studies reflect real-world environments.

Thirteen out of the 28 studies (46%) included in this review are published as pre-prints at time of writing, so have not yet been formally peer-reviewed raising additional concerns about overall quality and the potential for results to change prior to formal publication.

4 | DISCUSSION

This review summarises evidence regarding the airborne transmission of SARS-CoV-2 via aerosols from three study types as follows: epidemiological, air sampling and virological. The collective results from the epidemiological analyses of SARS-CoV-2 clusters or outbreaks suggests that aerosol transmission may play a role, amongst other transmission routes, however there is considerable uncertainty regarding this role and its relative contribution to overall transmission. Air sampling studies provide evidence that SARS-CoV-2 RNA is detectable in a proportion of samples collected in clinical and non-clinical areas, however the viability and infectivity of the virus in these environments was poorly investigated. Of three studies that attempted to culture virus from positive air samples, only one was successful in a limited number of samples. Evidence from two virological studies suggest viability of the virus in aerosols with plausibility for transmission, however given the controlled laboratory nature of these studies it is unclear if this translates to real-world environments.

Retrospective analyses from epidemiological studies provides low quality evidence of possible transmission in seven out of eight studies; however, these studies are limited in the data that they can provide and are at an inherently high risk of bias. A novel mathematical model applied to two of the described clusters (restaurant described by Liu et al. and choir described by Hamner et al.)[39] further proposes theoretical evidence for aerosol transmission being a reasonable cause of the high number of infections seen in these clusters. An additional epidemiological study, published since completion of the literature search within this review, further highlights the possibility of SARS-CoV-2 transmission by faecal aerosol.[40] There is substantial uncertainty regarding both the potential for aerosol transmission and its relative contribution to the spread of the virus. The majority of studies in this review acknowledged that aerosols may play a contributory, but not an exclusive role, with a number further noting enclosed environments and poor ventilation as potentially contributing factors. A modelling analysis by Miller et al.[41] of the environmental and contextual factors influencing the choir cluster described by Hamner et al.[39] further supports these theories. No included study identified aerosol transmission as the sole potential source of transmission and in all studies spread could have also occurred through other modes. Kutter et al.[2] and Gralton et al.[1] highlight that modes of transmission of respiratory viruses are unlikely to be mutually exclusive, with the three forms likely contributing in varying degrees depending on the virus in question. The significant contribution of aerosol transmission is well-recognised for certain pathogens (such as measles)[4]; however, the role of aerosols, and their relative contribution to the transmission of other respiratory viruses such as influenza and SARS-CoV is contentious and widely debated.[2,42,43] This uncertainty is reflected in clinical guidelines for the care of individuals with respiratory viruses frequently including a range of precautionary measures, particularly during the conduct of AGPs.[2]

The results of the air sampling studies and evidence under laboratory conditions of sustained detection from the virological studies within this review indicate that SARS-CoV-2 transmission via aerosols is possible. However, the detection of the virus in the air through PCR assays merely indicates presence and does not provide information regarding viability or infection risk.[3] Only three studies within this review attempted to culture the virus from positive PCR-detected air samples,[17,23,36] with one noting successful cultivation in a limited number of samples (on days 5 and 6 of culturing).[36] An additional study conducted by Lednicky et al.[44] published since completion of this evidence summary, has further shown virus cultivation (on days 2–4 of culturing) from air samples taken in the hospital room of two Covid-19 patients; air was sampled at a distance of at least 2 metres from the patients. The use of supplementary virus culture provides greater insight to the viability of the virus overall, with positive cultures providing plausible evidence of clinical risk. However, it is noted that such studies are notoriously challenging to complete and results may be impacted by other parameters or methodologies used.[45,46] Therefore, a failure to culture SARS-CoV-2 in these studies may either reflect the challenges in these study types or accurately indicate low pathogen levels. Additionally, it is suggested that the longer the incubation period and time to culture growth is indicative of lower viral loads and accordingly reduced infectivity.

A further important consideration in the transmissibility of respiratory viruses is the contribution and effect of environmental factors such as relative humidity, temperature and radiation.[46] A number of the epidemiological studies within this review noted that poor ventilation or air recirculation may have contributed to the spread of the virus, with another also citing low temperatures in a factory setting as a potential contributing factor.[9,13,28,33] The potential for this contextual transmission of SARS-CoV-2 has been acknowledged by the WHO,[3] and within theoretical assessments of the potential role of airborne transmission to the Covid-19 pandemic.[47,48] However, these reports have emphasised that, should airborne transmission occur, it is likely to be opportunistic, with such environments playing a facilitator role.[47,48] These reports also note that the reproduction rate for SARS-CoV-2 appears substantially lower than other established airborne viruses such as measles,[47] which is often cited as being between 12 and 18.[49]

Investigations of the relative contribution that each mode of transmission makes to the spread of specific respiratory pathogens is a particularly challenging area of research.[2,4] Study designs involving direct human transmission are naturally ethically flawed; in their absence a myriad of experimental designs are employed, each with clear advantages and disadvantages in its ability to definitively answer such a research question.[2] Therefore, conclusions about the likely modes of transmission, and their relative contribution, are typically made with consideration of a broad and multidimensional evidence-base. The form of evidence-base typically takes a considerable degree of time to mature, and often draws conclusions of mixed transmission routes, with different routes predominating depending on specific contexts such as environmental setting or exposure time.[4] Such an evidence-base is currently lacking in terms of the potential for the spread of SARS-CoV-2 via aerosol transmission, but more robust conclusions may be drawn as additional studies are published in this rapidly emerging area. In the context of the ongoing Covid-19 pandemic, and citing some of the limited evidence-base reported here, certain scientists have suggested that the precautionary principle should therefore apply.[50]

5 | CONCLUSION

The results of this review present a collection of evidence from a range of study designs regarding the potential for airborne transmission of SARS-CoV-2 via aerosols. Limited, low quality evidence from a small number of retrospective epidemiological studies suggests possible aerosol transmission of SARS-CoV-2. Furthermore, results from air sampling and virological studies add some plausibility to the potential for SARS-CoV-2 to transmit via aerosols, with limited evidence of clinical infectivity. Overall, while there is some evidence to suggest a potential for SARS-CoV-2 to transmit via aerosols, it is uncertain what contribution it makes, relative to other transmission modes (droplet and contact), to the Covid-19 pandemic and whether such transmission is context dependent, for example low temperature, poorly ventilated or enclosed environments. Additional well-conducted studies, across the spectrum of experimental designs, would provide greater insight into this research question.

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AUTHOR CONTRIBUTIONS

Laura Comber: Investigation, formal analysis, writing—original draft. Kieran Walsh: Investigation, writing—original draft. Eamon O Murchu: Investigation, writing—original draft. Paul G. Carty: Investigation, formal analysis. Linda Drummond: Writing, reviewing and editing. Cillian De Gascun: Writing, reviewing and editing. Máire A. Connolly: Writing, reviewing and editing. Susan M. Smith: Writing, reviewing and editing. Michelle O'Neill: Supervision, writing, reviewing and editing. Máirín Ryan: Supervision, writing, reviewing and editing. Patricia Harrington: Supervision, writing, reviewing and editing. All authors attest they meet the ICMJE criteria for authorship.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ORCID

Laura Comber https://orcid.org/0000-0003-2752-6558

Eamon O Murchu https://orcid.org/0000-0003-3926-0179

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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