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Learning from Covid-19 to Control Droplet & Airborne Transmitted Disease in Healthcare Environments

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Abstract

Aim
From a literature review, to ascertain what controls can be recommended to mitigate spread of Covid-19 to health-workers.

Methods
Using PubMed, a key-word search produced 82 articles, 14 of which we used to study transmission and controls recommended to mitigate nosocomial spread. We used Biological control guidance from WHO, EU and statistics from Health Protection Surveillance Centre (HPSE) publications.

Results
Surface fomite transmission was reported to be less than by droplet or aerosol. The search indicates that provision of negative pressure ventilation, isolation zones and local exhaust ventilation, in Covid-19 wards, would likely mitigate spread to health-carers.

Conclusion
Engineering controls including placing suspected or confirmed patients in airborne-infection isolation rooms (AIIR), maintaining adequate ventilation, and using physical barriers to prevent transmission between patients and health-workers are recommended. Use of administrative controls and environmental engineering, having personal-protective-equipment (PPE) as the final line of protection, is advocated to protect health-workers from SARS-CoV.

Introduction

The aim of this study is to ascertain from a literature review what controls can be recommended to mitigate spread of Covid-19 to health care workers. The EU directive 2000/54/EC on the protection of workers from risks of exposure to biological agents requires employers to identify associated hazards, assess risks and implement control measures resulting from the assessment.

Based on the data, health-workers are proportionately more infected, and many are hospitalised, treated in ICU or die of Covd-19. The number of infected health care workers (HCW) in Ireland notified to the Health-Protection-Surveillance-Centre (HPSC) is 11722 of 71019(16.59%) up to 21/11/2020. Three hundred and eighty-seven (3.3%) of Covid-19 HCW cases were hospitalised and fifty-nine (15.2 %) of these were treated in ICU. (Table A)

The national Covid-19 incidence is 71019 of 4,977,400[1] (1.4%), to 21/11/2020. Among HCWs the incidence is 11722 of 118090[2] (9.92%); i.e. 7 times greater than the general population.

Table A: Summary of healthcare worker COVID-19 cases notified to HPSC, week 10 (01/03/2020 - 07/03/2020) - week 47 (15/11/2020 – 21/11/2020), Ireland, (n=11,722).

Characteristics of HCW COVID-19 cases	**Number**	**%**
Total number of COVID-19 cases	71,019	
Total number of HCW cases	11,722	16.59
Median age (IQR)	41 (31-50) years	
Total number hospitalised	387	3.3
Total number admitted to ICU	59	15.2*
The median age (IQR) of HCW in ICU	51 (44-59) years	
Total number of deaths	8**	0.07
The median age (range) for deaths	54 (30-68) years	

**This relates to hospitalised cases and it is 0.5% of all HCW cases. **Seven confirmed and 1 probable COVID-19 case.*

Of 3480 healthcare worker Covid-19 cases notified to HPSC between weeks 32 to 48, 2020, 2313 (66.5%) were transmitted in the healthcare setting or close contact with a confirmed case. (Table B). Jones et al report that evidence suggests 20% of SARS-CoV-2 infections among patients in UK hospitals and up to 89% of infections among HCWs may have originated in hospitals[3].

Table B: Healthcare worker Covid-19 cases notified to HPSC, Ireland, by mode of transmission, from week 32-week 48, Ireland, (n=3480)

Mode of transmission	Number of HCW cases	Proportion of all HCW cases (%)
Healthcare setting acquired: staff	1163	33.4
Close contact with a known confirmed case	1040	29.8
Community transmission	733	21
Healthcare setting acquired: patient*	110	3.2
Travel related	40	1.2
Under investigation	394	11.4

*Requires data validation.

HSE Health Protection Surveillance Centre. www.hpsc.ie

Our objective is to review attempted approaches at reducing the rate of Covid-19 transmission in the healthcare setting, the safety requirements and recommend controls to mitigate spread to healthcare staff.

Methods

A systematic review was conducted of Covid transmission & controls in the healthcare setting, using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria. We used an open date strategy up to November 2020 for searching the literature. The search was made on the PubMed database.

The search terms used are as follows:

(SARS AND Transmission AND health workers AND engineering controls), which yielded 30 articles and 5 from their references.

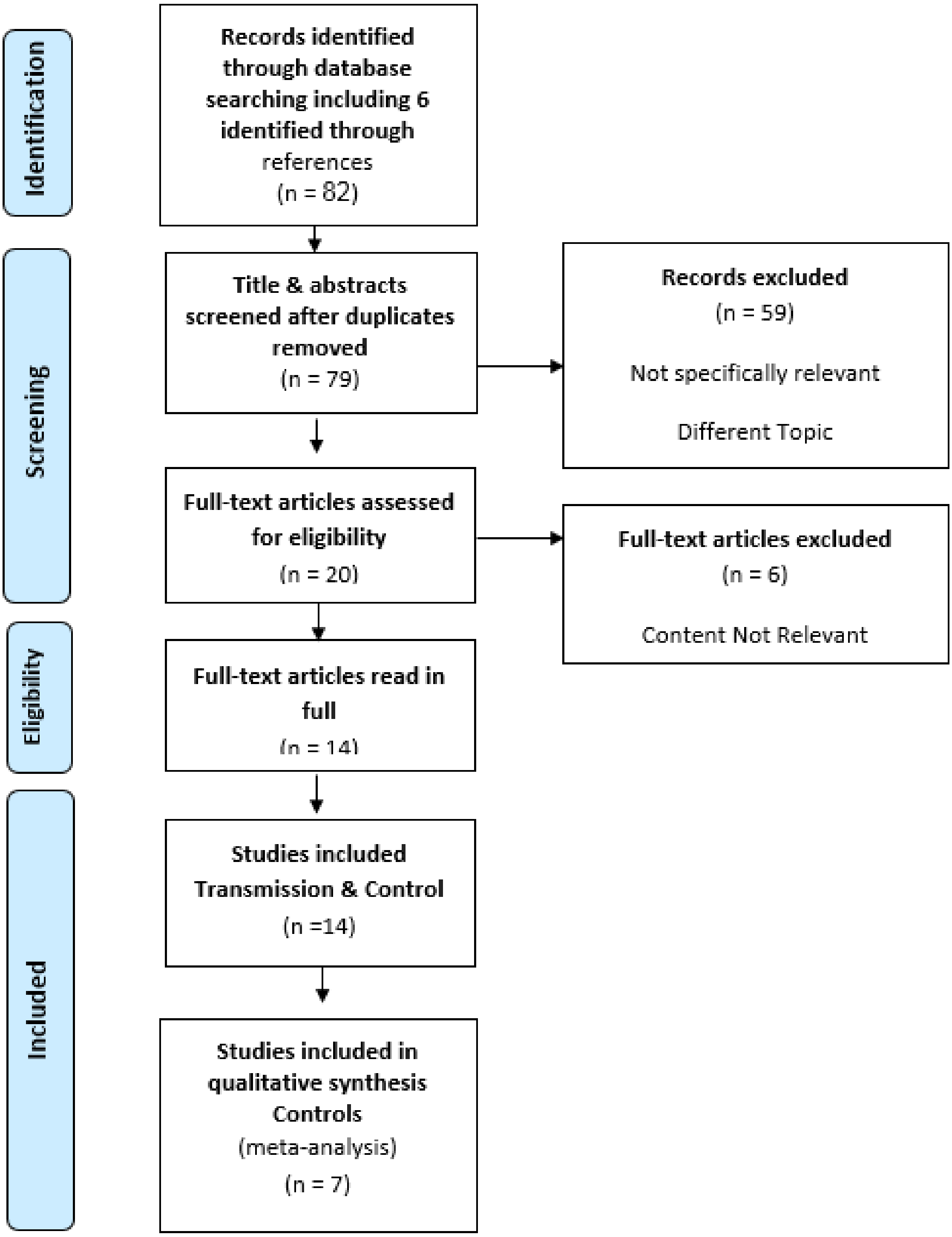
OR (SARS AND Local exhaust ventilation), which yielded 2 articles.

OR (SARS AND Healthcare Facilities AND Control AND Health-workers AND Transmission), which yielded 44 articles.

As per the PRISMA Diagram fig 1, we identified 14 original articles dealing with nosocomial coronavirus transmission and control for inclusion in this review. We also consulted EU, World Health and Centre for Disease Control (CDC) publications related to control of Biological agents.

Figure 1: PRISMA 2009 Flow Diagram**.**

(Covid-19, HCW, Transmission, Control) – PUB Med 82, Grey and H&S guidance 5 – Total 87



Results

Table C summarises the results of the review of 14 PubMed articles in terms of means of nosocomial transmission and recommended controls. The findings of these articles suggest droplet and aerosol virus transmission is greater than fomite. In regard to controls they contain original research into the role of ventilation, negative pressure isolation zones, local exhaust ventilation (LEV) systems and filtration. They indicate that LEV controls both aerosols and droplets.

Table C: Results of the review of 14 PubMed articles.

Author	**Location**	**HCW risk stats**	**Ventilation measures**	**Local Exhaust Ventilation**	**LEV method**	**Droplet mode**	**Airborne mode**	**Fomite mode**	**Negative pressure**	**Filter Air or drops**
Li Y	Honk Kong		1	1	Head height & floor exhaust.		1		1	
Phu H T	USA		1	1	Aerosol Hood	1	1		1	1
Borro L	Vatican		1	1	Above mouth exhaust	1	1			
McDonald L	Toronto		1						1	1
Lai H Y	USA		1	1	Aerosol box	1			1	1
Matava C	Toronto		1	1	Portable air extractor	1	1		1	1
Segar C D	USA			1	Suction containment chamber	1	1		1	
Xiao S	Honk Kong						1	1		
Bahl P	USA					1	1			
Park S H	Korea						1			
Song Z G	China		1			1		1	1	
Yu IT	Honk Kong						1			
Christian MD	Toronto		<u>1</u>			<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>	<u>1</u>
Jones NK	UK	<u>1</u>								
Total		1	8	6		8	10	3	8	5

Of 14 PubMed literature reviewed articles related to nosocomial transmission and control:
1 considers epidemiological transmission of Covid-19 to HCWs. 8 recommend ventilation measures to control spread of the virus while 6 recommend forms of local exhaust ventilation. 8 articles consider droplet and 10 consider airborne nosocomial transmission and 3 consider fomite transmission. 8 advocate ventilation systems including negative pressure isolation rooms, while 5 recommend methods of droplet or air filtration.

Transmission

Our data suggests that SARS virus transmission can be by droplet, airborne or fomite routes. Xiao et al concluded from modelling scenarios, of airborne, and fomite transmission routes, that Sars-CoV was less probable to transmit via the fomite route alone. The airborne route was predominant, but it was more probable that the virus could transmit in combined routes[4]. A systematic review for evidence of horizontal distance travelled by respiratory droplets found that seasonal CoVs were more commonly emitted in aerosols than in droplets, even through normal tidal breathing. The maximum distance recorded was 8 meters. SARS-CoV-2 can be detected in the air 3 hours after aerosolisation. They conclude that droplet precautions alone are not appropriate for SARS-CoV-2.

Evidence supports airborne precautions for the safety of health-workers[5]. Yu et al studied the association between location and the probability of airborne infection in a residential complex. Using Computational Flow Dynamic (CFD) modelling they conclude that airborne spread from an index case appears to explain a large community outbreak of SARS. They recommend consideration of prevention and control[6]. A hospital study, using CFD simulations, showed that there was an association between the concentration decay from an index patient's bed and the spatial SARS infection pattern. This provided environmental evidence of an airborne transmission route for SARS[7].

Prevention and Control

McDonald et al studied the SARS outbreak among health-workers. Facilities were constructed or retrofitted to create SARS evaluation centres. Dedicated entrances, exits and marked patient pathways segregated patients. Adequate ventilation, air exhaust & negative pressure infection isolation rooms were provided, to reduce droplet or airborne transmission. No transmission was reported in those facilities[8]. Another study describes controls in AIIRs. The directional top-to-bottom airflow in AIIRs greatly reduced the transmission of respiratory droplets and the high air change rate prevented the accumulation of virus aerosols. No virus was detected on the face shields or coveralls of HCW's or from air samples inside the AIIRs. They identified surface contamination with SARS-CoV-2 in isolated wards. None of 290 HCWs was infected in AIIRs at that hospital[9].

Exhaust Ventilation

Prototype controls are being devised to contain and extract airborne and droplet particles directly from patient's breathing zones. A number of these have been constructed and tested experimentally.

Li Y et al studied a 40-bed hospital ward, having 4 cubicles, with 1 infected patient. Using CFD simulation, they studied the distribution of virus laden bio-aerosol concentrations at a height of 1.1m at the time of infection and after modifications involving provision of new floor level and bed-head level exhausts. They correlated the results of aerosol concentration zones with persons who subsequently became infected and later charted the reduction or elimination of aerosol contamination after modifications. They assumed the virus source was the index patient. They found an association between the spatial infection pattern and the dispersion of virus-containing bio-aerosols from the index patient.

Study of the ward air distribution design at the time of exposure was necessary to provide environmental evidence of airborne transmission and to identify and develop engineering control systems[7]. In simulated hospital scenarios, another investigated transmission using CFD. They felt that heating, ventilation and air-conditioning may have a role in spreading the virus from infected persons' exhalation. A LEV system placed above the coughing patient's mouth, simulated in the hospital room, was associated with a complete reduction of infected droplets within 0.5 seconds following the cough event. The LEV system completely reduced the index computed for the bed next to the spreader, with a decreased possibility of contagion. The presence of a LEV system located near the patient markedly reduced droplet and airborne contaminant dispersion[10]. Similarly, another describes a portable high flow air extractor, high efficiency filtration unit allowing up to 235 L/ s, used to transform a regular room into a negative pressure room.

The high-efficiency-particulate-filter (HEPA) filter removes 99.97% of all airborne pathogens > 0.3 µm. The filtered air can be adapted to an existing exhaust system or vented outside. Placed 25–30 cm above the manikin's head, the extractor device was 99% effective at removing aerosols near the source, resulting in no levels detected at the clinician's head. During an uncovered cough, the extractor was 97% effective[11]. This technique is consistent with current recommendations from the CDC to augment room air exchanges[12].

We found that LEV containment hoods greatly mitigate dispersion of droplets and airborne virus from the patient's breathing zone. They are connected to exhausts which extract and filter contaminated aerosol and droplets, mitigating transmission outside the hood. Phu et al designed and evaluated a portable negative pressure hood with HEPA filtration to protect health care workers treating patients with transmissible respiratory infections. The hood provides access to patients via iris ports. Less than 1% of aerosol particles generated in the hood escape. They propose that enclosing patients in negative pressure systems with HEPA filtration would address concerns regarding non-invasive positive pressure ventilation for Covid-19 patients. Such devices may provide isolation spaces, without the need for building HVAC system reconfiguration. A portable negative pressure system to isolate patients in existing environments reduces the potential for aerosol transmission. This prototype has a flow profile similar to fume or inexpensive residential kitchen ventilation hoods. It can collect large droplets via impaction and aerosol particles via HEPA filtration. Room air enters the hood at rates exceeding the flow rate of all non-invasive ventilation (NIV) procedures[13]. Another describes a device for infected aerosols. It is a single use suction-assisted local aerosol containment chamber, which creates a negative pressure microenvironment surrounding the patient's head and upper torso. The device ships flat and folds into a chamber[14]. Finally, another describes an aerosol box which protects healthcare providers against aerosol spread during endotracheal intubation. It is a partial negative pressure container which facilitates the removal of droplet nuclei and captures them with a ULPA filter to reduce the risk of exposure. It captures particles of 0.12µm or higher at an efficiency of 99.97%[15].

Discussion

Regarding transmission to health workers, it appears that airborne and droplet containing virus may cause fomite deposition as well as directly infect mucus membranes. Also, it appears that airborne virus can travel long distances exceeding 8 meters and remain airborne for over 3 hours.

Per EU directive 2000/54/EC, SARS Cov-2 is a group 3 biological agent. Hence extract air from the workplace should be filtered. Air pressure should be negative unless the risk assessment indicates otherwise. The risk of exposure must be reduced to protect the workers concerned, by designing work processes and engineering control measures, to avoid or minimise the release of biological agents into the workplace. Where exposure cannot be otherwise avoided, individual protection measures must be provided[18].

The WHO, hospital control guidance, recommends that probable SARS cases should be isolated and accommodated in descending order of preference as follows: Negative pressure rooms with the door closed, Single rooms with their own bathroom facilities, Cohort placement in an area with an independent air supply, Exhaust system and bathroom facilities[19].

Our data indicates that high-efficiency particulate air filtration in a rigid flow geometry system is greatly more efficient in collecting particles than are N95 respirators. In most settings, engineering controls are preferred to PPE, which is regarded as the least effective method of exposure mitigation. Our results suggest negative pressure hoods can protect health care workers from airborne disease transmission. We believe the engineering bench tests and simulated hospital environments described provide strong support for the efficacy of a number of recently developed localized negative pressure systems in response to the COVID-19 pandemic.

This may be the first attempt to review findings suggesting the benefit of various environmental engineering solutions in mitigating hospital Covid-19 transmission to HCWs. Standardised testing is lacking for validation of competing research protocols. We have no specific data in relation to what standardised engineered infection control exists in health care facilities.

We consider this review illustrates the benefit of environmental engineering controls in health care settings to mitigate nosocomial transmission of Covid-19. The use of mechanical ventilation may be a better, more compliant and safer strategy which works to mitigate transmission and PPE should be the last line of defence.

Engineering controls including placing suspected or confirmed patients in airborne-infection isolation rooms, maintaining adequate ventilation, and using physical barriers to prevent transmission between patients and HCWs are recommended. This systematic approach using administrative controls and environmental engineering, having PPE as the final line of protection is advocated to prevent Sars-CoV transmission to health-workers[16,17].

Declaration of Conflicts of Interest:
This is to declare that none of the Authors have any conflict of interest in relation to this article.

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