
Original Article

Selecting Controls for Minimizing SARS-CoV-2 Aerosol Transmission in Workplaces and Conserving Respiratory Protective Equipment Supplies

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Abstract

With growing evidence of inhalation of small infectious particles as an important mode of transmission for SARS-CoV-2, workplace risk assessments should focus on eliminating or minimizing such exposures by applying the hierarchy of controls. We adapt a control banding model for aerosol-transmissible infectious disease pandemic planning to encourage the use of source and pathway controls before receptor controls (personal protective equipment). Built on the recognition that aerosol-transmissible organisms are likely to exhibit a dose–response function, such that higher exposures result from longer contact times or higher air concentrations, this control banding model offers a systematic method for identifying a set of source and pathway controls that could eliminate or reduce the need for receptor controls. We describe several examples for workers at high risk of exposure in essential or return to work categories. The goal of using control banding for such workers is to develop effective infection and disease prevention programs and conserve personal protective equipment.

Keywords: aerosol transmission; control banding; COVID-19; hierarchy of controls; occupational safety and health; SARS-CoV-2; workplace exposure

Introduction

There is growing evidence of inhalation of small infectious particles as an important mode of SARS-CoV-2 transmission (Asadi *et al.*, 2020; Bahl *et al.*, 2020; Heinzerling *et al.*, 2020; Meselson, 2020; Morawska

and Cao, 2020; Wang and Du, 2020). The COVID-19 pandemic is likely to continue for some time and workplace outbreaks continue to occur, even in locations where community transmission has decreased. From that perspective, occupational hygienists have an obligation

to consider hazardous SARS-CoV-2 aerosols in workplace risk assessments and to encourage employers to utilize well-studied and proven source and pathway control strategies for minimizing aerosol exposures.

We describe a qualitative risk assessment and control selection approach for protecting employees from aerosol-transmissible diseases, such as COVID-19, and illustrate how such an approach could be used during an ongoing pandemic where essential workers must remain at work and, eventually, most employees must physically return to work.

We currently lack the tools to adequately measure employee exposures to inhalable concentrations of infectious organisms. In contrast to airborne chemical exposures, well-validated air sampling and analytic methods for infectious aerosols are not readily available. While many chemical agents have well-established occupational exposure limits, the infectious dose by inhalation exposure route has not been identified for most organisms. These factors limit our ability to quantify exposure levels and correlate exposures with health outcomes. Without these key risk assessment ingredients, our ability to evaluate occupational risk and effectiveness of controls for infectious aerosols is limited.

When the levels of exposure to a workplace hazard are not known or difficult to measure and workplace exposure limits are not available or difficult to construct, occupational health and safety professionals may resort to qualitative tools, such as control banding, for determining which occupations, tasks, and industries present the highest risk for workers (Zalk and Heussen, 2011). These tools can also be useful in determining the best control options for lowering exposures. Absent a pandemic, human-generated infectious respiratory diseases generally occur in workplaces such as healthcare, childcare, protective services, laboratory research, and funeral services among those with the highest exposure likelihood (Haagsma *et al.*, 2012). During a pandemic, when community spread of infection is high, exposures could occur in all workplaces where there is close contact or prolonged time spent with clients, patients, customers, or coworkers.

Control banding is a qualitative method for determining the degree of risk for occupations and job tasks. First used in the pharmaceutical industry, control banding allowed identification of appropriate measures for reducing exposures to novel materials for which few toxicologic or epidemiologic data were available (Zalk and Nelson, 2008). More recent applications have been in regulatory settings where quantitative exposure limits are unavailable (Russell *et al.*, 1998) and for novel substances such as nanomaterials where toxicologic

data are rare (Paik *et al.*, 2008). Identifying the correct ‘hazard band’ requires knowledge of toxicity (of the substance or a close relative), the nature of exposure (physical state, route of entry, likely airborne concentration), and duration of exposure. Lacking quantitative data, descriptive values may be used, for example: low, medium, high concentration; and short, medium, long duration of exposure. The hazard band is accompanied by a required or recommended set of control measures, commensurate with the level of risk and informed by the hierarchy of controls.

Sietsema *et al.* (2019) proposed a control banding method for aerosol-transmissible diseases, such as COVID-19, for two reasons: (i) to identify those jobs at highest risk and (ii) encourage the use of source and pathway controls before resorting to personal protective equipment (PPE), for the ultimate goal of conserving PPE for those in the highest risk categories. Their approach uses four risk groups to represent toxicity, ranging from R1 for agents not associated with disease in healthy adults to R4 being agents likely to cause serious or lethal human disease. This is combined with an exposure band that derives from three categories of duration and three exposure likelihood categories. Once these factors are determined one of three control bands (A, B, or C) will result for a workplace or set of job tasks, which then informs the selection of appropriate source, pathway, and receptor controls.

The goals of this work are to describe how the Sietsema *et al.* (2019) control banding model is applicable to the current COVID-19 pandemic and illustrate, using several case examples, how decisions about workplace controls for aerosol transmission are facilitated by this model and can inform the safe reopening of workplaces.

Methods

Control banding steps

Identify organism toxicity

Lacking a dose–response function for infectious diseases, Sietsema *et al.* (2019) propose instead applying the National Institutes of Health (NIH) risk groups developed for laboratory biosafety applications (National Institutes of Health, 2019). The risk group represents the ‘toxicity’ of an organism, in its broadest sense, categorizing an organism by its ability to cause disease in humans, the seriousness of that disease, and the availability of preventive (e.g. vaccines) or therapeutic (e.g. drugs) interventions. The NIH Office of Science Policy has determined that SARS-CoV-2 is a Risk Group 3 organism (National Institutes of Health, 2020). For a fraction of the population, COVID-19 is a very serious and

sometimes lethal disease for which there are not yet any well-established preventive or therapeutic interventions.

Determine exposure

An employee's exposure to a hazardous airborne chemical depends on two variables: (i) air concentration and (ii) length of time in contact with that air concentration. For SARS-CoV-2, we lack routine and widely available quantitative methods for sampling airborne infectious organism concentrations and there is uncertainty regarding the infectious dose required to cause disease.

We know that infectious dose varies for different organisms, suggesting there is some exposure level (concentration of infectious aerosols) required to elicit infection and disease (Ward *et al.*, 1984). As well, infectious dose varies with route of entry. While aerosol exposure has only rarely been explored experimentally, the infectious dose by aerosol inhalation for some respiratory organisms such as influenza is lower than that by other exposure routes (Lednický *et al.*, 2010; Belser *et al.*, 2015).

Setting aside these issues, as well as disease outcome differences by age, gender, race, comorbidities, and other host factors, we assume that SARS-CoV-2 requires a certain 'dose' of infectious particles to achieve respiratory infection that results in viral shedding. We assume that a cumulative dose resulting from a short exposure to a high aerosol concentration will be just as likely to lead to infection as one resulting from a longer exposure (such as an 8-h work shift) to a lower concentration.

Thus, exposure is a function of (i) the likelihood that the job involves person-to-person interactions with potentially infected people and (ii) the total duration of time—over the course of a day or shift—such person-to-person interactions occur. Likelihood of exposure ranges from 'unlikely' to 'possible' to 'likely', while duration ranges from 0 to 3, 3 to 6, or >6 h. The latter was predicated on an 8-h shift; this variable could also be expressed as percent or another metric appropriate to the job. These variables are used to determine the level of exposure as shown in Table 1, where E1 represents low likelihood of exposure, E2 possible exposure of short or medium duration and E3 likely exposure of medium or long duration.

The exposure level (E1, E2, or E3) is then combined with the organism risk ranking to identify the relevant 'control band' for a job (Table 2).

Select controls

Each control band requires implementing preventive measures starting with the source, then pathway and finally receptor (Fig. 1).

Table 1. Exposure determined by likelihood of exposure and daily duration.

Likelihood of exposure	Daily duration (number of potential exposure hours per 8 h workday)		
	D1 (0–3 h)	D2 (3–6 h)	D3 (>6 h)
L1 (unlikely)	E1	E1	E1
L2 (possible)	E2	E2	E3
L3 (likely)	E2	E3	E3

Table 2. Control band.

Exposure rank	Risk rank			
	R1	R2	R3	R4
E1	A	A	A	B
E2	A	B	B	C
E3	A	B	C	C

Control band A, which is reserved for Risk Group 1 organisms or unlikely exposures for Risk Group 2 and 3 organisms, requires the use of only source and then, if necessary, pathway controls. Receptor controls (personal protective equipment) are not appropriate for jobs that fall into this band. Jobs falling into control band B are those where exposure is unlikely but the toxicity (risk group) is severe, or where exposures are possible or likely and risk is moderate (Risk Groups 2 and 3). Controls for band B should be focused primarily on sources and then, if necessary, pathways; receptor controls might be necessary but only as a final resort. Only in control band C, reserved for possible and likely exposures and higher risk groups, should receptor controls, such as respiratory protection, be considered, after source and pathway controls, of course (Table 3).

The most effective and appropriate set of control strategies must start with those that prevent or minimize release of a hazard, in this case, the infectious aerosol, at the source, i.e. an infected individual. During a pandemic source control is complicated by the fact that every person present in a workplace—coworkers, customers, visitors, etc.—could be a source of infectious aerosols. Aerosolization or reaerosolization of infectious particles from a surface could also be a source.

With SARS-CoV-2 we are further hampered by evidence that a great deal of transmission appears to occur pre- and asymptotically. Thus, we must assume that every person in a workplace is a potential source. The prevalence of pre- and asymptomatic transmission ranges from 20 to 60% in some settings (Kimball, 2020; Mizumoto *et al.*, 2020; Wei *et al.*, 2020).



Figure 1. Source, pathway, and receptor hierarchy of controls.

Table 3. Selection of controls by control band.

Control band	Control options
A	Source controls first Pathway controls second—generally prudent Receptor controls—generally not necessary
B	Source controls first—may require multiple options Pathway controls second—may require multiple options Receptor controls—only if source and pathway controls are not effective
C	Source controls first—may require multiple options Pathway controls second—may require multiple options Receptor controls—may be prudent

Examples of source controls might be:

- Eliminate all in-person interactions by requiring customers to conduct their business via phone, internet, or some remote method, in combination with delivery or drive-by pickup. This type of control has been applied successfully in some locations to the purchase of perishable goods such as groceries and prepared food.
- Conduct employee health screenings prior to arrival at work, to identify and exclude those potentially infected (note: this may not identify pre- or asymptomatic individuals).
- Clean surfaces and eliminate activities that may contribute to reaerosolization of deposited infectious particles (e.g. the use of compressed air to remove particulates or clean surfaces).
- Eliminate person-to-person meetings by requiring remote communication methods.
- Adjust work schedules to limit the number of people present in a workplace at any one time.
- Reorganize congregate locations (lunchrooms, bathrooms, conference rooms, entrances, and exits) to limit the number of people.

If source controls do not adequately prevent or minimize employee exposure to infectious aerosols, by limiting likelihood or duration, then pathway controls must be implemented in tandem. Such controls eliminate or limit the movement of infectious aerosols from the source (infected person) to the receptor (employee).

Pathway controls might include:

- Place barriers that interrupt the flow of infectious aerosols between the source and receptors.
- Increase the amount of dilution air (air changes per hour).
- Designate ‘hot’ and ‘cold’ or ‘clean’ and ‘dirty’ zones that separate infectious sources from receptors.
- Incorporate distancing into settings with many sources, keeping in mind that particles from coughs and sneezes can easily travel beyond 6 ft.
- Utilize local exhaust ventilation to capture infectious aerosols at the source.
- Use high-efficiency portable air cleaners to remove particles near the source and improve air mixing throughout a space.

Pathway controls are, in general, more difficult to design and implement correctly. For example, increasing the number of air changes per hour (dilution ventilation) can lower the overall concentration of particles in a space, but may not be effective at lowering particle concentrations near the source. Industrial hygienists do not typically employ dilution ventilation for the control of hazardous aerosols from industrial processes, because it will not protect workers near the source. Relying on dilution ventilation allows distribution of particles throughout a space and could increase everyone’s exposure to particles in comparison to local exhaust ventilation, which removes particles at the source. In a space with a good directional airflow design using multiple intakes and exhausts that ensure good air mixing, dilution ventilation may be effective. Enclosing the process or partial enclosure in combination with local exhaust can be much more effective at protecting everyone, including those nearest the source.

Where people are the source of infectious aerosols, a better option might be the use of portable air cleaners equipped with high-efficiency filters, if the construction

of local exhaust ventilation is not immediately possible. Care must be taken in the placement of such devices, as they may change the movement of air throughout the space and raise exposure for some workers while lowering it for others. The use of barriers to enclose or divide the space into smaller compartments may be useful in tandem with portable air cleaners, but this also requires careful design to ensure proper mixing within the enclosed spaces.

It would be appropriate to consult with an expert in the design of such control systems. Many occupational hygienists have the expertise and equipment to assess aerosol generation and movement throughout a workplace. Some have expertise in the design and evaluation of local exhaust ventilation systems and similar types of source controls.

As this discussion illustrates, multiple pathway controls may be necessary to ensure that either exposure likelihood and/or exposure duration are minimized.

Only as a last resort, receptor controls might be necessary. In the case of a pandemic, when receptor controls such as personal protective equipment are in short supply, every effort must be made to reserve supplies for workers whose exposures place them in control band C and for workers whose jobs cannot easily be controlled using only source and pathway methods.

For workplaces where employees may be at higher risk of serious illness for reason of age or preexisting conditions, it may be appropriate to adjust the control band or select additional control measures.

Results

Because healthcare workers are one group at highest risk, while source and pathway controls should be utilized and can be effective at lower exposures, personal protective equipment, such as respirators, will also be necessary. As examples, we consider control banding for some essential workers who have been working throughout the pandemic as well as those whose risks may be high after stay-at-home orders are lifted. Controls for front-line healthcare workers are not addressed here; these can be found in US and European guidelines ([Centers for Disease Control and Prevention, 2020b](#); [European Centre for Disease Prevention and Control, 2020](#)).

Transportation workers

Transportation is considered an essential industry, important for ensuring that other essential workers can make it to work. Bus and subway drivers have constant

contact with others, work directly with the public, provide personal assistance to customers, spend most of their worktime in an enclosed vehicle and are often in moderate proximity to people (within an arm's length) ([Department of Labor, 2019](#)).

Exposure likelihood is very high (L3) for these jobs, given the potential for the presence of many pre- or asymptomatic infected people. Transit workers spend most of their working hours in contact with people (D3), thus their exposure level is E3 ([Table 1](#)). When combined with a risk rank of R3 for COVID-19 these workers fall into control band C.

In workplace settings we would deploy local exhaust ventilation to capture and remove hazardous aerosols at the source, but this is an impractical solution for transit passengers. In the longer term, retrofitting buses or subway cars with localized ventilation that captures and transports aerosols away from each seat might be a possibility. Limiting the number of passengers would limit the airborne concentration of infectious particles, thus lowering the overall aerosol concentration to which passengers and drivers are exposed. This may be a workable solution but would require running more buses or cars more frequently, which would require more drivers, a perhaps infeasible solution in the short term.

Pathway controls, i.e. preventing the flow of particles from passengers into the driver's breathing zone, may be more amenable to inexpensive and effective solutions. One example might be the isolation of the driver in a separately ventilated enclosure. There are well-established methods that would allow communication between passengers and drivers. Automated solutions for collecting money and dispensing tickets are already available on most mass transit, thus limiting requirements for direct contact. If well-designed, complete enclosure would eliminate exposure to passenger-generated aerosols and lower exposure to L1 (unlikely), thus decreasing exposure to E1 and moving this job into control band A. In this case, there is no need to resort to further pathway controls or to require the use of any personal protective equipment.

Warehouse workers

The work of stock or warehouse clerks involves daily and frequent face-to-face discussions, constant contact with others, working with groups or teams and spending about half of the time in moderately close proximity to other people (at arm's length) ([Department of Labor, 2020a](#)).

For the purposes of this example, we assume that exposure to infected coworkers is likely (L3), given the

amount of pre- and asymptomatic transmission reported for COVID-19. We assume a daily duration of exposure from 3 to 6 h (D2) since some of the shift probably involves working on one's own. This yields an exposure of E3 and results in control band C.

Source control (limiting emission of aerosols from infected coworkers) may be possible by symptom screening, with follow-up testing (if available), to limit the number of infected people present. Screening may not identify people who are pre- or asymptomatic, however.

Isolation of workers using enclosures is not feasible for this type of work, where employees must move throughout a large space. Limiting worker interactions by employing remote methods for communication, such as phones or walkie-talkies, may be a better solution. Requiring employees to work at a designated distance from each other, limiting the number of employees in a particular area or on a shift, changing the manner in which work and teams are organized are all methods that will interrupt the pathway from potential sources to receptors. Increasing the rate of dilution ventilation (air changes per hour) or adding local exhaust ventilation may not have much impact on the generation of aerosol from sources (coworkers) continually moving throughout a space, although dilution ventilation could lower the overall concentration in smaller spaces, such as lunchrooms, toilets, and other communal locations.

If source and pathway controls do not lower the likelihood of exposure from L3 to L1 it may be necessary to decrease the duration of exposure from D2 by decreasing the length of shifts, for example. As before, lowering the likelihood of exposure to L1 decreases the overall exposure to E1 and moves this job into control band A. No receptor controls (personal protective equipment) should be necessary.

Ophthalmologist

One of the first physicians who called attention to and subsequently died of exposure to SARS-CoV-2 in China was an ophthalmologist (Parrish *et al.*, 2020). A large majority of the work of an ophthalmologist requires close, face-to-face interactions with patients while conducting eye examinations and surgeries, administering medications, or performing diagnostic or clinical tests. The work involves assisting and caring for others, communicating, and working directly with patients and coworkers and coordinating the work and activities of others. The work involves close contact with others 100% of the time, daily face-to-face discussion, dealing with members of the public, working with a group or team, potential exposure to diseases or infections, and

being in very close proximity to people (nearly touching) more than 70% of the time (Department of Labor, 2020b). Given the number of pre- and asymptomatic people with COVID-19 and the lack of definitive tests, every patient could be infected. It may be possible to require patients to wear a surgical mask, which may limit some number of larger droplets but will not prevent the emission of small particles during breathing or talking. It may also be possible limit the number of patient interactions by tele-medicine.

It may be possible to devise some form of local exhaust ventilation, such as a slot hood, near the patient, which would remove particles from the immediate vicinity. Such controls can be very efficient at removing hazardous aerosols if well designed and operated at appropriate flow rates. A barrier between the patient and physician might also be appropriate, in combination with local exhaust ventilation, to direct particles away from the breathing zone. This would require some careful design by someone with expertise in ventilation design along with evaluation, using tracer particles or gas for example, to ensure that the configuration is effective at removing particles from the space. Using a barrier without ventilation may prevent movement of particles into the breathing zone of the physician during the exam but would not limit particle distribution and buildup in the room. Small particles can remain suspended in air for considerable time; after several infected patients, the concentration in a small exam room may exceed the infectious dose.

If source controls do not adequately lower aerosol concentrations, then pathway controls may also be necessary. One option might include the addition of a standalone high efficiency particulate air-filtered air cleaner to the room, which would enhance air movement throughout the space while also collecting infectious particles. The sizing and placement of such an air cleaner are important, to ensure adequate and effective air movement and cleaning. Again, consultation with an expert may be necessary. It is important that air and particles are drawn away from the source and not through the breathing zone of the physician.

Another option would be to build a ventilated enclosure around the patient or the physician. The former would require a filter to clean exhausted air, while the latter would require filtering the air before it enters the enclosure. Either of these options may be infeasible if they interfere with conduct of an eye examination.

Given the close contact nature of an eye examination, it may be necessary to employ personal protective equipment such as respiratory protection in addition to the source and pathway controls described. An N95 filtering

facepiece respirator would be the minimum level of respiratory protection recommended for this exposure. Eye protection would also be recommended, as recent data suggest that eye exposure may lead to upper respiratory infection (Li *et al.*, 2020a). Goggles or a face shield in combination with a filtering facepiece respirator or a respirator with full-face protection would be appropriate, although these may interfere with communication and conduct of an eye exam.

This workplace does not easily lend itself to source and pathway controls, but there may be some innovative approaches we have not considered. Resorting to receptor controls (respiratory protection) without at least making some effort to design enclosures or deploy ventilation would not be appropriate. Respirators are uncomfortable to wear for long periods of time, interfere with communication and may make it difficult to conduct eye examinations and tests.

Police patrol officer

Police patrol officers may engage in a wide range of activities, including responding to emergencies, maintaining order, protecting people and property, enforcing laws, providing aid, testifying in court, conducting patrols, directing traffic, issuing citations, etc. They work directly with the public, resolve conflicts and negotiate with people, communicate with supervisors, peers, and subordinates, assist and care for others, train and teach others, develop and build teams, coach and develop others. They are involved in daily face-to-face discussions, constant contact with others, deal with external customers, deal with unpleasant or angry people, work in groups or teams and spend at least half of their time very close (nearly touching) to people (Department of Labor, 2020c).

Police officers have many interactions with many different members of the public and coworkers, any of whom could be infected and pre- or asymptomatic. Exposure is likely (L3) and duration is either D2 (3–6 h) or D3 (>6 h). Either duration yields an exposure level of E3. Combined with a risk level 3 organism, this job falls in control band C.

Given the unpredictable nature of an officer's interactions with coworkers and the public, source controls may not be feasible. For people being held in the back seat of a patrol car, it should be possible to prevent aerosol movement to the front seat area using a barrier. Such barriers may not be possible in other workplace locations, however. The best options may be limiting the amount of time spent in close contact with people and limiting the number of contacts. It may

be necessary to reconfigure the job to reduce the time spent doing close-contact tasks. Changing the configuration of desks, increasing or changing ventilation, adding more circulation and in-room filtration, utilizing more remote methods for communicating with the public are all possible methods for reducing contact time and number of contacts. Pathway controls would appear to be more feasible and effective than source controls for this type of job. In some cases where contact time and number of contacts cannot be reduced, personal protective equipment (a fit-tested respirator) may be necessary.

Discussion

The most credible information about transmission of SARS-CoV-2 is that it occurs person-to-person (Centers for Disease Control and Prevention, 2020a). Transmission in group settings appears to be highly likely, such as families, meetings, religious and social gatherings, and funerals (James *et al.*, 2020; Li *et al.*, 2020b; Pan *et al.*, 2020; Pung *et al.*, 2020; Tong *et al.*, 2020).

Some of the risk factors for workers appear to be (Dyal, 2020; Gan *et al.*, 2020; Kinner *et al.*, 2020; Koh, 2020; Koh and Goh, 2020; Lan *et al.*, 2020; McMichael *et al.*, 2020; Moriarty, 2020; Payne *et al.*, 2020; Semple and Cherrie, 2020; Tobolowsky *et al.*, 2020):

1. Contact with many people—either members of the public (e.g. healthcare workers, emergency responders, transportation workers, grocery store workers, correctional and immigration officers, retail salespeople, taxi drivers, casino workers, and cruise ships) or coworkers (warehouses, meatpacking plants, healthcare settings, and naval ships).
2. Close prolonged face-to-face interactions with people—either members of the public (ophthalmology, dentistry, elder care, emergency, and acute patient care) or coworkers (police, emergency responders, retail workers, casino workers, manufacturing workers, and construction workers).
3. Contact with suspected or confirmed infected people such as in healthcare settings and COVID-19 testing sites, where infection risks are higher for those with more contacts, more close contacts, more prolonged contacts, or contact during symptoms or aerosol-generating procedures.

Baker *et al.* (2020), using data from the O*NET database to identify occupations likely to be exposed to diseases or infections, found that 77% of healthcare

support and healthcare practitioners and technical staff reported exposure at least once a week and greater than 90% reported exposure at least once a month. Exposure at least once a month were reported by 52% of protective or personal care services workers, 23–32% of workers in community and social services and education, training and libraries, and 16–21% of building and grounds, cleaning and maintenance, and office and administrative support workers. Obviously, these data represent non-pandemic circumstances; the likelihood for exposure during a pandemic will be considerably higher for these and other occupations, especially during accelerating phases of the community infection.

In Wuhan China, from the beginning of the pandemic in December 2019 to 18 February 2020, a total of 1316 healthcare workers were infected, 5.1% of all cases. The attack rate in healthcare workers (145 per 10⁶ people) was almost 3.5 times greater than for the general population (42 per 10⁶). From 23 January to 1 February the attack rate among healthcare workers reached 507 per 10⁶ (Pan *et al.*, 2020). A report from the Chinese Center for Disease Control and Prevention evaluated 72 314 cases throughout China through 11 February 2020; 3.8% (1716) were healthcare workers; 15% were severe cases and 5 deaths resulted (Wu and McGoogan, 2020). Lan *et al.* (2020) conducted an observational study of confirmed COVID-19 cases reported in Hong Kong, Japan, Singapore, Taiwan, Thailand, and Vietnam government investigation reports during the first 40 days after the first local transmission case was reported. Of 690 local transmission, 15% (103) were considered possibly work-related, with the highest frequency of cases in healthcare workers (22%), drivers and transport workers (18%), services and sales workers (18%), cleaning and domestic workers (9%), and public safety workers (7%). High-risk occupations included car, taxi, and van drivers, retail salespeople, domestic housekeepers, religious personnel, construction laborers, and tour guides. Early in the transmission period the workers most likely to be infected were retail salespeople, driver, construction laborers, religious professionals, tour guides, and receptionists. Later in the transmission period, healthcare workers, drivers, housekeepers, police, and religious personnel were at highest risk of infection.

These data support the cases selected to illustrate jobs where SARS-CoV-2 exposures are likely to be high and control banding could be useful for identifying source and pathway controls.

We were unable to find any workplace guidelines that adequately accounted for the role of aerosol transmission, i.e. the inhalation of aerosols near a source. Many are overly focused on contact transmission, a relatively

unimportant mode of transmission, and assume that droplet transmission by propulsion into the mouth, eyes, or nose from symptomatic individuals coughing or sneezing is the only particle-related transmission mode.

Guidance from the [European Agency for Safety and Health at Work \(2020\)](#) notes the importance of applying the hierarchy of controls, starting with eliminating the risk followed by minimizing worker exposure and finally personal protective equipment. Recommendations for minimizing exposure rely on reducing physical contacts, increasing distance, using barriers, and reducing close contact time. There is no discussion of ventilation, but there is recognition that the placement of barriers could introduce new hazards.

While recognizing that inhalation of infectious particles may be a possible route of exposure, the United States Occupational Safety and Health Administration (OSHA) COVID-19 recommendations describe only very general categories of controls within the hierarchy, but do not address their applicability or feasibility in the context of risk level. Limited attention is paid to methods for limiting aerosol transmission other than a brief mention of ventilation and somewhat greater attention to respirators, despite the latter being at the bottom of the control hierarchy. OSHA's four risk levels describe exposure in the context of contact with known or suspected sources of COVID-19 and frequency of such contacts, but do not recognize the importance of contact time, airborne concentration, or proximity (Department of Labor, 2020d).

The control banding approach described here, which focuses on the likelihood and duration of exposure, is more useful for estimating risks. Thinking about the control hierarchy in the context of source, pathway, and receptor controls offers a more nuanced approach for considering interventions, when every worker is a potential source. The focus on combining multiple source and pathway controls ensures that most workers will not be required to wear personal protective equipment.

This model, as is true for similar models used for other hazardous exposures where occupational exposure limits are not available, has not undergone rigorous validation. While this is an important weakness, a model built on the well-established principles of dose–response and a hierarchy that emphasizes source and pathway controls are the core principles of occupational hygiene decision-making, which often requires a combination of well-informed science and professional judgment.

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Conflict of interest

The authors declare no conflict of interest relating to the material presented in this article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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