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Classification of aerosol-generating procedures: a rapid systematic review

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ABSTRACT

In the context of covid-19, aerosol generating procedures have been highlighted as requiring a higher grade of personal protective equipment. We investigated how official guidance documents and academic publications have classified procedures in terms of whether or not they are aerosol-generating. We performed a rapid systematic review using preferred reporting items for systematic reviews and meta-analyses standards. Guidelines, policy documents and academic papers published in english or french offering guidance on aerosol-generating procedures were eligible. We systematically searched two medical databases (medline, cochrane central) and one public search engine (google) in march and april 2020. Data on how each procedure was classified by each source were extracted. We determined the level of agreement across different guidelines for each procedure group, in terms of its classification as aerosol generating, possibly aerosol-generating, or nonaerosol-generating. 128 documents met our inclusion criteria; they contained 1248 mentions of procedures that we categorised into 39 procedure groups. Procedures classified as aerosol-generating or possibly aerosol-generating by ≥90% of documents included autopsy, surgery/postmortem procedures with high-speed devices, intubation and extubation procedures, bronchoscopy, sputum induction, manual ventilation, airway suctioning, cardiopulmonary resuscitation, tracheostomy and tracheostomy procedures, non-invasive ventilation, high-flow oxygen therapy, breaking closed ventilation systems, nebulised or aerosol therapy, and high frequency oscillatory ventilation. Disagreements existed between sources on some procedure groups, including oral and dental procedures, upper gastrointestinal endoscopy, thoracic surgery and procedures, and nasopharyngeal and oropharyngeal swabbing. There is sufficient evidence of agreement across different international guidelines to classify certain procedure groups as aerosol generating. However, some clinically relevant procedures received surprisingly little mention in our source documents. To reduce dissent on the remainder, we recommend that (a) clinicians define procedures more clearly and specifically, breaking them down into their constituent components where possible; (b) researchers undertake further studies of aerosolisation during these procedures; and (c) guideline-making and policy-making bodies address a wider range of procedures.

INTRODUCTION

Humans ordinarily expel particles from the mouth and nose while breathing, talking and coughing, as well as during certain healthcare procedures. These particles are formed of water and mucus that contain infectious material, including viruses. Exhaled particles may range in size between 0.01 and 1000 µm, depending on mechanism of generation and site of origin, with up to 308 600 particles being produced per cough.[1 2] Procedures (eg, intubation) can change the volume, size, distribution and speed of particles expelled as well as changing their origin from different parts of the respiratory tract.

Viruses lose viability at different rates, depending on the virus family and functional surface characteristics, droplet expulsion mode and stability, environment, and time.[3–5] Susceptible persons in the vicinity of an infected individual can therefore become infected through multiple particle routes, including inhaling close to the source or touching and transferring particles that have landed on surfaces. Expelled particles can spread widely in a room in a short time after a cough,[6–8] and cases are recorded where infectious material has dispersed through ventilation systems or windows.[9] Infectious particles may also be dispersed by other routes such as toilet flushing or doffing protective clothing.[10 11]

Infection control practices have traditionally classified disease transmission as occurring through 'contact' (implying direct physical transfer), 'droplet' or 'airborne' routes.[12] Larger particles settle in a reasonably short distance, and are referred to as 'droplets' in the infection control context. Smaller particles can travel as aerosols on air currents, remaining in the air for longer and distributing over a wide area.[13]

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus that causes coronavirus disease 2019 (COVID-19) can be transmitted via aerosols.[14] Therefore, medical procedures that generate aerosols can lead to transmission of the virus to personnel performing the procedures as well as to bystanders. For that reason, physicians and other healthcare providers are understandably concerned about aerosol-generating procedures, infection risk and the need for appropriate personal protective equipment.[15 16]

Infection control practices include wearing an appropriate ensemble of personal protective equipment as well as using proper procedures for donning and doffing. The critical items of personal protective equipment in relation to aerosolised infectious matter are respiratory protective devices, specifically filtering facepiece respirators such as FFP2, FFP3 or N95 type masks. These should be used together with other items as appropriate, such as gloves, gowns, shoe covers and eye protection equipment. Furthermore, personal protective equipment should be applied together with other hazard control measures in the hierarchy of controls, such as cohorting COVID-19 positive patients, surface cleaning and ensuring adequate air ventilation.[17 18]

The WHO and other authorities recommend the use of respirators when performing aerosol-generating procedures on patients with known or suspected COVID-19, but deem standard surgical masks (which do not seal to the face and are not considered respirators) adequate for routine care not involving aerosol-generating procedures.[12] The question of what is or is not an aerosol-generating procedure is therefore of considerable importance in the COVID-19 context, especially when certain items of personal protective equipment, such as filtering facepiece respirators, are in short supply.

Our specific research question was: how have official guidance documents and academic publications classified procedures in terms of whether or not they are aerosol-generating?

METHODS

We conducted a rapid systematic review in line with the Cochrane Interim Guidance for Rapid Reviews.[19] Our review was registered as a COVID-19 Rapid Evidence Review with the National Collaborating Centre for Methods and Tools at McMaster University (https://www.nccmt.ca/knowledge-repositories/covid-19-evidence-reviews/7).

We have reported this review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses reporting criteria for systematic reviews where appropriate (online appendix 1).[20] Our review is part of a 'Programme of Research and Training in Occupational Medicine' by SSt's team at the University of Alberta. It is also one of a suite of reviews on personal protective equipment initially commenced as part of the Oxford COVID-19 evidence series and edited by TG.

We included documents in English or French (read fluently by the authors, reflecting Canada's bilingualism) and published since 1 January 2000. We deemed eligible for inclusion peer-reviewed journal articles, pre-prints, conference proceedings and grey literature from a variety of sources such as healthcare organisations, agencies and government departments. To be included, documents had to report on procedures and state whether they are aerosol-generating, possibly aerosol-generating or not aerosol-generating.

Systematic literature searching was conducted from 26 March 2020 to 8 April 2020. We searched for relevant literature in Medline (1946 to present via OVID), in Cochrane Central (from inception to present) and in Google using English and French keywords, as well as performing searches on English and French websites. These search strategies are detailed in online appendix 2. We also considered documents previously known to the authors, or that were shared with us by others after we had made known our intention of writing the present systematic review.

A data extraction form was developed and piloted, and used to extract citation details, definitions of aerosol-generating procedures used in the source documents and lists of procedures that were classified (as aerosol-generating, possibly aerosol-generating or not aerosol-generating). Extracted data for each source document were verified by a second researcher, and any discrepancies found in the verification stage were adjudicated by a third researcher. Quantitative data on procedures identified as aerosol-generating, possibly aerosol-generating or not aerosol-generating were then generated by giving procedures one count for each document in which they were thus classified.

Different source documents used slightly different terminology to describe procedures. We combined similar procedures into a total of 39 procedure groups based on author consensus, using an iterative process of categorising the records and creating groups until we felt that the existing groups sufficiently captured the data. The resulting procedure groups are shown in table 1.

For aerosol-generating procedures, we developed groupings of likely aerosol sources using the same process, resulting in 12 aerosol source groups (table 2).

For each procedure group, we calculated the percentage of agreement among the contributing sources on how it was classified (aerosol-generating, possibly aerosol-generating, or not aerosol-generating). We considered 90% or greater agreement on a procedure group as aerosol-generating or possibly aerosol-generating as very strong consensus, and 80% or greater agreement as strong consensus. Where there was a high level of disagreement between sources, or where a procedure was mentioned by only a few sources, we considered explanations.

Table 1	Procedure groups
1	Airway suctioning
2	Autopsy
3	Breaking closed ventilation systems (intentionally or unintentionally)
4	Bronchoscopy
5	Cardiopulmonary resuscitation
6	Chest physiotherapy
7	Colonoscopy
8	Coughing
9	ENT and neurosurgery
10	Nitrous oxide (Entonox) administration
11	GI endoscopy (not further specified)
12	Handling soiled laundry
13	High-frequency oscillatory ventilation
14	High-flow oxygen therapy
15	Intra/extra pulmonary high-frequency oscillation devices
16	Intubation and extubation procedures
17	Labour and delivery
18	Lung function testing
19	Manipulation of masks
20	Manual ventilation
21	Mechanical ventilation
22	Mechanical insufflation and exsufflation
23	Nasogastric tube insertion
24	Nasopharyngeal aspirate
25	Nasopharyngeal and oropharyngeal swabbing
26	Nasopharyngoscopy or laryngoscopy
27	Nebulised or aerosol therapy
28	Non-invasive ventilation
29	Oral and dental procedures
30	Prone positioning
31	Sputum induction
32	Suction of body fluids (not further specified)
33	Supraglottic airways
34	Surgery/postmortem procedures with high-speed devices
35	Thoracic surgery and procedures
36	Toilet use and flushing
37	Tracheostomy and tracheostomy procedures
38	Upper GI endoscopy
39	Vacuum cleaning

ENT, ear, nose and throat; GI, gastrointestinal.

Table 2	Aerosol source groups
1	Autopsy
2	Cleaning tasks
3	Gastrointestinal (not further specified)
4	Inhaled therapy
5	Labour and delivery
6	Oronasal
7	Upper gastrointestinal
8	Laboratory
9	Lower gastrointestinal
10	Patient care
11	Tracheobronchial
12	Wound/invasive procedure

RESULTS

Description of dataset

Our searches identified 162 potentially eligible documents of which 153 remained after elimination of duplicates. Of these, 25 documents were excluded because they did not meet the eligibility criteria, leaving 128 documents that were included in our rapid systematic review. Online appendix 3 lists the references of the included documents. Online appendix 4 details the excluded documents.

We used documents from nine countries including Canada (n=60), UK (n=9), France (n=8), USA (n=4), Australia (n=2), Ireland (n=2), Luxembourg (n=2), China (n=1) and New Zealand (n=1), as well as two documents from European agencies and societies and six documents from the WHO. We did not assign a country of origin for academic journal publications. Our included documents comprised 91 documents in English and 37 documents in French. The documents were from academic journals (n=31), supranational agencies (eg, the WHO) (n=7), government agencies (including regional and federal health boards and departments dedicated to public health, infection prevention, seniors' health and long-term care, paediatric health and critical illness) (n=72) and professional associations (respiratory therapists and physiotherapists predominating) (n=17). Most included documents were published within the last five years.

Forty-three of the 128 documents in our sample provided definitions of aerosol-generating procedures, as listed in online appendix 5. These documents generally agreed that an aerosol-generating procedure was any intervention or procedure that could produce aerosols capable of transmitting diseases. Some documents specified that these interventions had to involve manipulation of a patient's airway, while others did not. Some documents also specified that aerosol-generating procedures were only those procedures capable of producing aerosols in excess of what is produced when a patient is coughing, breathing or talking, while others made no mention of such a threshold.

The top 10 procedure groups classified as aerosol-generating, by greatest number of mentions across all included source documents (ie, a frequency count), were: intubation and extubation procedures, airway

suctioning, bronchoscopy, non-invasive ventilation, nebulised or aerosol therapy, cardiopulmonary resuscitation, sputum induction, tracheostomy and tracheostomy procedures, manual ventilation, and autopsy. These and further procedure groups are presented in online appendix 6. The likely aerosol sources for the procedures listed as aerosol-generating were assigned by us as follows: tracheobronchial (n=711 procedure mentions), inhaled therapy (n=111), oronasal (n=81), autopsy (n=33), wound/invasive procedure (n=27), cleaning tasks (n=13), patient care (n=13), upper gastrointestinal (GI) (n=5), GI—not further specified (n=2), laboratory (n=2) and lower GI (n=1). Online appendix 7 details all mentions of the procedures deemed to be aerosol-generating.

The top 10 procedure groups listed as possibly aerosol-generating were: chest physiotherapy, nasopharyngeal aspirate, nasopharyngeal and oropharyngeal swabbing, nebulised or aerosol therapy, high-frequency oscillatory ventilation, non-invasive ventilation, tracheostomy and tracheostomy procedures, airway suctioning, coughing, intubation and extubation procedures, and mechanical ventilation. These, further procedure groups, and the associated frequency counts are presented in online appendix 8. The likely aerosol sources for the possible aerosol-generating procedures were: tracheobronchial (n=74 procedure mentions), oronasal (n=26), inhaled therapy (n=17), wound/invasive procedure (n=5) and patient care (n=3). Online appendix 9 lists all procedures described as possibly aerosol-generating procedures in the source documents. Online appendices 10 and 11 present data on procedures which were deemed by the source documents to not be aerosol-generating. For these procedures, we assigned no aerosol source.

Ambiguity in procedure classification

The nature of a given procedure was sometimes ambiguous, making its assignment to a procedure group difficult. This was discussed at length among the authors and led to several iterative refinements of the procedure groups, careful review and sometimes reassignment of procedures to procedure groups.

For example, an Oxylator (a portable ventilator powered by an oxygen cylinder and used in cardiopulmonary resuscitation) may be used with either manual or mechanical ventilation. In such cases, we assigned what we felt was the predominant group; for example, manual ventilation, in the case of the Oxylator.

Another challenge was ambiguous description. This was a common issue in procedures relating to suctioning. Some source documents used the specific term 'airway suctioning', while others listed a procedure as 'suctioning' or 'open suction', without an anatomical location. In some documents, 'open suction' was listed within respiratory physiotherapy interventions, included in a section discussing respiratory droplets, or clearly listed alongside other respiratory procedures (especially intubation, extubation and tracheostomy procedures), allowing us to classify it confidently as 'airway suctioning'. In other documents, the term 'suction' was found in a heterogeneous list (eg, before 'intubation' but after 'autopsy'). In these cases, we could not comfortably assume that 'suction' necessarily meant airway suctioning. Several documents used the term 'suction of body fluids' as a procedure, but we could not find any context clues indicating which body fluids were being suctioned; we therefore grouped those procedures as 'suction of body fluids (not further specified)'. Online appendix 12 details this reasoning further.

The determination of the aerosol source was also sometimes open to interpretation. For example, we assigned an aerosol source of 'oronasal' to the procedure group 'nasopharyngoscopy or laryngoscopy', as we deemed this the most likely source of aerosol. However, if such procedures trigger a cough, then aerosols of 'tracheobronchial' origin would be generated.

Procedure groups with high consensus

Table 3 lists the 14 procedure groups on which there was very strong (90% or more) consensus among source documents that the constituent procedures were definitively aerosol-generating or possibly aerosol-generating. It also lists three additional groups of procedures (high-frequency oscillatory ventilation, coughing and mechanical ventilation) for which there was strong (80% or more) consensus. As shown in column 3 of table 3, some of these procedures were mentioned in most of the source documents, while others were mentioned less often.

Procedure groups with poor consensus

Table 4 lists four groups of procedures on which there was less than 80% consensus. In one of these (oral and dental procedures), consensus was 78%. In the other three (upper GI endoscopy, thoracic surgery and procedures, and nasopharyngeal and oropharyngeal swabbing), there appeared to be substantial disagreement among sources. Possible reasons for disagreement are considered in the Discussion section.

For the controversial procedure groups, one needs to look in more detail; for example, for the oral and dental procedures group, which we recognise is heterogeneous, the procedures deemed to be aerosol-generating often specified the use of a high-speed device, including the use of air turbines, air/water syringes, scopes, high-speed drills, or other power tools or high-speed handpieces; and the use of ultrasonic scalers. Other oral and dental procedures described as aerosol-generating included dental care, dental examinations and the use of propellant anaesthetic freezing sprays such as oral lidocaine.

In contrast, oral and dental procedures labelled as not aerosol-generating did not specify the use of high-speed devices. We found the following procedures listed as not aerosol-generating: dental examinations, oral suctioning or suctioning of the oropharynx, hand scaling with

Table 3 Procedure groups classified as 'aerosol-generating' or 'possibly aerosol-generating' with high levels of agreement (80% or more of sources)

Procedure group	Aerosol source	N of sources mentioning procedures in this group	n (%) of sources that classified procedures in this group as aerosol-generating	n (%) of sources that classified procedures in this group as possibly aerosol-generating	n (%) of sources that classified procedures in this group as not aerosol-generating
Autopsy	Autopsy	33	33 (100)	0 (0)	0 (0)
Surgery/postmortem procedures with high-speed devices	Wound/invasive procedure	14	14 (100)	0 (0)	0 (0)
Intubation and extubation procedures	Tracheobronchial, oronasal	119	114 (96)	5 (4)	0 (0)
Bronchoscopy	Tracheobronchial	94	89 (95)	2 (2)	3 (3)
Sputum induction	Tracheobronchial	64	60 (94)	2 (3)	2 (3)
Manual ventilation	Tracheobronchial	56	52 (93)	2 (4)	2 (4)
Airway suctioning	Tracheobronchial, oronasal	103	92 (89)	6 (6)	5 (5)
Cardiopulmonary resuscitation	Tracheobronchial	74	66 (89)	3 (4)	5 (7)
Tracheostomy and tracheostomy procedures	Tracheobronchial	65	57 (88)	8 (12)	0 (0)
Non-invasive ventilation	Tracheobronchial	89	78 (88)	8 (9)	3 (3)
High-flow oxygen therapy	Inhaled therapy	37	32 (86)	4 (11)	1 (3)
Breaking closed ventilation systems (intentionally or unintentionally)	Tracheobronchial	13	11 (85)	2 (15)	0 (0)
Nebulised or aerosol therapy	Inhaled therapy	91	75 (82)	9 (10)	7 (8)
Nasopharyngoscopy or laryngoscopy	Oronasal	16	12 (75)	2 (13)	2 (13)
High-frequency oscillatory ventilation	Tracheobronchial	39	27 (69)	9 (23)	3 (8)
Coughing	Tracheobronchial	18	10 (55)	5 (28)	3 (17)
Mechanical ventilation	Tracheobronchial	15	8 (53)	4 (27)	3 (20)
Chest physiotherapy	Tracheobronchial	46	23 (50)	14 (30)	9 (20)
Nasopharyngeal aspirate	Oronasal	29	13 (45)	12 (41)	4 (14)

Percentages were rounded to the nearest full percentage point.

suction, non-surgical extractions, removable denture stages, removal of caries using hand excavation or a slow-speed handpiece, and orogastric tube placement.

Procedure groups with very limited evidence

Table 5 lists 15 groups of procedures which were each mentioned in fewer than 10 source documents. Some of these (eg, ear, nose and throat and neurosurgery) were classified as aerosol-generating procedures whenever they were mentioned while others (such as nasogastric tube insertion) were classified inconsistently as

Table 4 Procedure groups with high levels of disagreement among sources on aerosol-generating status

Procedure group	Aerosol source	N of sources mentioning procedures in this group	n (%) of sources that classified procedures in this group as aerosol-generating	n (%) of sources that classified procedures in this group as possibly aerosol-generating	n (%) of sources that classified procedures in this group as not aerosol-generating
Oral and dental procedures	Oronasal	40	31 (78)	0 (0)	9 (22)
Upper gastrointestinal endoscopy	Upper gastrointestinal	10	5 (50)	2 (20)	3 (30)
Thoracic surgery and procedures	Wound/invasive procedure	14	4 (29)	2 (14)	8 (57)
Nasopharyngeal and oropharyngeal swabbing	Oronasal	34	9 (27)	10 (29)	15 (44)

Percentages were rounded to the nearest full percentage point.

Table 5 Procedure groups with limited evidence (<10 sources)

Procedure group	Aerosol source (if procedures aerosol-generating or possibly aerosol-generating)	N of sources mentioning procedures in this group	n (%) of sources that classified procedures in this group as aerosol-generating	n (%) of sources that classified procedures in this group as possibly aerosol-generating	n (%) of sources that classified procedures in this group as not aerosol-generating
ENT and neurosurgery	Wound/invasive procedure	3	3 (100)	0 (0)	0 (0)
GI endoscopy (not further specified)	GI (not further specified)	2	2 (100)	0 (0)	0 (0)
Intra/extra pulmonary high-frequency oscillation devices	Tracheobronchial	3	2 (67)	1 (33)	0 (0)
Toilet use and flushing	Cleaning tasks	2	2 (100)	0 (0)	0 (0)
Vacuum cleaning	Cleaning tasks	2	2 (100)	0 (0)	0 (0)
Supraglottic airways	Tracheobronchial	1	1 (100)	0 (0)	0 (0)
Handling soiled laundry	Cleaning tasks	6	5 (83)	0 (0)	1 (17)
Prone positioning	Tracheobronchial	5	4 (80)	0 (0)	1 (20)
Mechanical insufflation and exsufflation	Tracheobronchial	4	3 (75)	1 (25)	0 (0)
Manipulation of masks	Oronasal	8	5 (63)	0 (0)	3 (37)
Lung function testing	Tracheobronchial	7	4 (57)	2 (29)	1 (14)
Suction of body fluids (not further specified)	Patient care	6	3 (50)	2 (33)	1 (17)
Colonoscopy	Lower GI	2	1 (50)	0 (0)	1 (50)
Nasogastric tube insertion	Oronasal	9	4 (44)	1 (11)	4 (44)
Nitrous oxide (Entonox) administration	–	2	0 (0)	0 (0)	2 (100)
Labour and delivery	–	1	0 (0)	0 (0)	1 (100)

Percentages were rounded to the nearest full percentage point. Totals may therefore not equal 100% exactly.
ENT, ear, nose and throat; GI, gastrointestinal.

aerosol-generating, possibly aerosol-generating or not aerosol-generating. However, the small number of source documents for these procedure groups means that no firm conclusions can be drawn.

DISCUSSION

This rapid systematic review has produced a number of key findings. First, we have reduced a lengthy list of procedures to 39 procedure groups, making the classification of such procedures easier. We have also developed a taxonomy of the likely sources of aerosols.

Second, we believe we have identified a substantial body of relevant literature and that this has allowed us to draw reasonably confident conclusions as to which procedures have been most frequently identified as being aerosol-generating.

Third, through a thorough search and synthesis of this literature, we have identified a number of procedures on which there is already high consensus that these are aerosol-generating or possibly aerosol-generating. In view of the seriousness of COVID-19 and the known occupational risk to healthcare workers, we recommend that the procedures listed in table 3 be treated as aerosol-generating procedures for the purposes of selecting personal protective equipment.

Fourth, we have identified a list of potential aerosol-generating procedures on which guidance appears to be sparse. Of particular note is the fact that certain very common procedures (such as colonoscopy and procedures relating to labour and delivery) were barely mentioned in our sample of 128 documents. It is possible that our search missed specialist publications, so a logical next step would be more specific searches for these procedures. If dependable literature addressing these cannot be identified, we recommend that professional and regulatory bodies note the list of procedures presented in table 4 and hold meetings to establish the current level of multidisciplinary professional consensus.

Finally, we have identified a small number of procedures (shown in table 4) on which there appears to be substantial disagreement. The groups ‘oral and dental procedures’ and ‘thoracic surgery and procedures’ were broad and each covered a range of procedures. Upper GI endoscopy was covered by only 10 documents, so more specific searching and arriving at expert consensus may be indicated for this procedure group, too. For the other contested procedure group (nasopharyngeal and oropharyngeal swabbing), we recommend that a process of achieving expert consensus be used, such as a modified Delphi method among a panel of relevant

experts who examine each of our 34 sources individually, ideally supplemented by an updated literature search.[21] Strengths of our paper include an extensive literature search, yielding a dataset that covers both academic and grey literature and also a very wide range of settings, authorities and jurisdictions. Furthermore, all data were at least double-checked. We believe this is the first systematic, international survey of guidance on aerosol-generating procedures.

This study has a number of limitations. The chief limitation is that we were working from secondary sources and were not resourced to go back to primary evidence on which recommendations would have been based. While we can have some confidence in widespread agreement among experts that a procedure is aerosol-generating, the reverse is not necessarily true. It is possible that procedures not listed in guidance documents as aerosol-generating may still produce aerosols, especially when those procedures are relatively new or where there has been no specific research to confirm or refute the hypothesis. The list in table 3 should therefore not be viewed as exhaustive.

Additionally, we could have categorised the various, slightly differing, descriptions of procedures that we found in the included source documents in a number of ways. While the procedure groups and aerosol sources described in our review represent the consensus of a diverse set of authors with expertise in the subject matter, in evidence synthesis methodology, and in medical taxonomy, our groupings are, in a sense, arbitrary and various different schemata may be equally valid.

Moreover, the frequency counting approach is at best an approximation of expert consensus; we counted each mention equally, but perhaps should not have. The documents we included were addressed to different audiences, developed with varying degrees of scholarly rigour, and they were sometimes based on one another or based on common sources.

We did not undertake a formal risk of bias assessment of our included documents, partly because no suitable tool could be identified and partly because our objective was to map the variation in recommendations across the full range of official guidance.

As noted above, some clinically relevant procedures received surprisingly little mention in our source documents. We therefore cannot conclude that our search, extensive as it was, led to a classification of aerosol-generating procedures that is complete for all clinical situations. In particular, colonoscopy as well as labour and delivery procedures will clearly require further exploration. There were other infrequently mentioned procedures which are performed in healthcare settings but are not medical in nature, such as vacuum cleaning and toilet flushing; these may nonetheless be relevant and would also require further specific attention.

The reader will also note that we found more Canadian resources than one might expect from Canada's share of the global economy and population. Likely, we fell victim to a degree of 'home country bias'—we searched globally, but our familiarity with Canadian resources may have meant that we have identified those more readily than others. We caution the reader to consider this, but at the same time want to propose that Canada can serve as a model Western society and that the considerations of Canadian health services are also applicable elsewhere.

A number of findings from this review prompt new hypotheses that should be taken forward. One theme that emerged, for example, is that various procedures deemed to be aerosol-generating were suggested to have the potential to trigger coughing, and coughing in itself was characterised as aerosol-generating in multiple source documents. For such procedures, triggering a cough might therefore be the mode of aerosol generation.

In this context, it is worth noting that coughing can aerosolise viruses. Jones and Brosseau proposed a model for evaluating the quality of evidence for aerosol transmission of an infectious disease, with three conditions: aerosol generation (containing pathogens), environmental viability, and access to target tissue (resulting in infection).[22] They found that there was strong evidence for aerosol transmission of influenza and severe acute respiratory syndrome (SARS), among other diseases. We can therefore draw from the literature on influenza and SARS with some confidence of its generalisability. There is specific evidence that influenza may be transmitted by coughing, which Huynh *et al* found to produce airborne particles containing viable virus; these particles can then be inhaled by others, especially in close proximity.[23] Lindsley *et al* examined exposure from coughing using breathing and coughing simulators and found that the breathing simulator would incur substantial exposure at a distance of 46 cm from the coughing simulator, but that distancing to 183 cm could reduce exposure by 92%.[24] However, another study using the same methodology demonstrated that cough particles spread throughout a room within several minutes, meaning anyone in the room may be exposed regardless of their location.[6]

Recent work in fluid dynamics has suggested that longstanding assumptions about how aerosols are generated, that is, that coughs produce aerosolised particles of respiratory secretions expelled in a direct trajectory, may underestimate the exposure risk. We now know that coughs and sneezes are primarily composed of turbulent gas clouds which contains droplets of various sizes, and which can travel 7–8 m.[7] Van Doremalen *et al* investigated the aerosol and surface stability of SARS-CoV-2 and compared it with SARS-CoV (the virus that causes SARS), finding them similar, supportive of aerosol and fomite transmission.[5]

If any procedure that triggers coughing is potentially associated with the generation of aerosols, the implications for personal protective equipment during the COVID-19 pandemic are profound, especially since coughing is a common symptom of COVID-19.[17] A study assessing the efficacy of different protective equipment showed that N95 respirators were effective protection

against aerosol exposure from a close-range cough, while surgical masks were inadequate.[12] Other laboratory studies have shown similar findings, notably that higher-grade personal protective equipment (N95 respirators) worn by both patients and healthcare workers reduced exposure to such particles.[5]

While the debate about aerosol-generating procedures in the context of COVID-19 has focused primarily on the question of when and how healthcare workers should select respirators, there are many other measures that should be taken to reduce viral transmission when undertaking a healthcare procedure or exposure that could generate aerosols. Systems-level modifications to facilities include optimising air ventilation and decreasing relative humidity.[25] Experiments with aerosolised SARS-CoV-2 in artificial saliva have shown it to be twice as stable as influenza at medium humidity (40%–60%), and to have longer viability in high humidity (68%–88%) compared with lower humidities.[26] Interventions clinicians can undertake personally include self-distancing (eg, from a coughing patient) and careful doffing of personal protective equipment. Consideration should also be given to continuous masking by staff and patients.[27]

In conclusion, this rapid systematic review has added to the evidence base for the classification of aerosol-generating procedures. While the literature has many gaps, we believe that there is sufficient evidence to confidently classify at least 19 procedure groups as aerosol-generating. To reduce dissent on the remainder, we recommend that (a) clinicians define procedures more clearly and specifically, breaking them down into their constituent components where possible; (b) researchers undertake further studies of aerosolisation during these procedures; and (c) guideline-making and policy-making bodies address a wider range of procedures.

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Competing interests QD-M reports grants from the Workers' Compensation Board of Alberta, during the conduct of the study. SSm reports other from 3M Canada Company, outside the submitted work. In addition, SSm has a patent P. Legare, G.E. Dwyer, A. Murphy, S.J. Smith 'Air filtration device' US Patent 9.744.493 and European Patent 2274067 (2008). issued, and a patent R.A. Abdulqader, S.C. Dodds, A.M. Gilman, A.D. Groth, C.P. Henderson, D.M. Maanum, L.V. Palaikis, N.A. Rakow, S.J. Smith, E. Evgeny, 'Filtering face-piece respirator including functional material and method of forming same' World Patent 201766284 (2015). issued. SSt reports grants from the Workers' Compensation Board of Alberta during the conduct of the study; personal fees from the Workers' Compensation Board of Alberta, personal fees from WorkSafeBC and personal fees from the Canadian Board of Occupational Medicine, outside the submitted work.

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