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Research paper

Development and validation of a tool to appraise guidelines on SARS-CoV-2 infection control strategies in healthcare workers

Ashwin Subramaniam, FRACP, FCICM, MMed [a, b, c, *], Mallikarjuna Ponnapa Reddy, FCICM, DDU [a, b, r], Umesh Kadam, MRCP (UK), FCCIM MSc [d, s], Alexander Zubarev, MD [a], Zheng Lim, MBBS [e], Chris Anstey, MSc (Stats), FANZCA, FCICM [f], Shailesh Bihari, FCICM, PhD [g], Jumana Haji, MD [h], Jinghang Luo, MBBS, MMed (ClinEpi) [i], Saikat Mitra, MD, FNB [j], Kollengode Ramanathan, MD, FCICM [j, k], Arvind Rajamani, FCICM [l], Francesca Rubulotta, MD, PhD, FRCA, FICM [m], Erik Svensk, MD, DESA [n], Kiran Shekar, FCICM, PhD [o, p, q]

[a] *Frankston Hospital, Frankston, VIC Australia;* [b] *The Bays Hospital, Mornington, VIC Australia;* [c] *Monash University, Frankston, VIC Australia;* [d] *Werribee Mercy Hospital, Werribee, VIC, Australia;* [e] *Austin Health VIC, Heidelburg, Australia;* [f] *Griffith University, University of Queensland, Qld Australia;* [g] *Flinders University and Flinders Medical Center, SA, Australia;* [h] *Aster CMI Hospital, Bangalore, India;* [i] *Western Health, VIC, Australia;* [j] *National University Hospital, Singapore;* [k] *Yong Loo Lin School of Medicine, National University of Singapore, Singapore;* [l] *University of Sydney, Nepean Clinical School and Nepean Hospital, Kingswood, NSW, Australia;* [m] *Anaesthesia and Intensive Care Unit, Imperial College London, London, UK;* [n] *Anesthesia and Intensive Care Unit, Sundsvall Hospital, Sundsvall, Sweden;* [o] *Adult Intensive Care Services, The Prince Charles Hospital, Brisbane, Queensland;* [p] *University of Queensland, Brisbane, Qld, Australia;* [q] *Bond University, Gold Coast, Qld, Australia;* [r] *Calvary Public Hospital, ACT, Canberra, Australia;* [s] *Casey Monash Hospital, Berwick, VIC, Australia*

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ABSTRACT

Background: Clinical guidelines on infection control strategies in healthcare workers (HCWs) play an important role in protecting them during the severe acute respiratory syndrome coronavirus 2 pandemic. Poorly constructed guidelines that are incomprehensive and/or ambiguous may compromise HCWs' safety.
Objective: The objective of this study was to develop and validate a tool to appraise guidelines on infection control strategies in HCWs based on the guidelines published early in the coronavirus disease 2019 pandemic.
Design, setting, and outcomes: A three-stage, web-based, Delphi consensus-building process among a panel of diverse HCWs and healthcare managers was performed. The tool was validated by appraising 40 international, specialty-specific, and procedure-specific guidelines along with national guidelines from countries with a wide range of gross national income.
Results: Overall consensus (≥75%) was reached at the end of three rounds for all six domains included in the tool. The Delphi panel recommended an ideal infection control guideline should encompass six domains: general characteristics (domain 1), engineering recommendations (domain 2), personal protective equipment (PPE) use (domain 3), and administrative aspects (domain 4-6) of infection control. The appraisal tool performed well across the six domains, and the inter-rater agreement was excellent for the 40 guidelines. All included guidelines performed relatively better in domains 1–3 than in domains 4–6, and this was more evident in guidelines originating from lower income countries.
Conclusion: The guideline appraisal tool was robust and easy to use. Engineering recommendations aspects of infection control, administrative measures that promote optimal PPE use, and HCW wellbeing were generally lacking in assessed guidelines. This tool may enable health systems to adopt high-quality

* Corresponding author.
E-mail addresses: ashwin.subramaniam@monash.edu (A. Subramaniam), malli_ponnu@yahoo.co.in (M. Ponnapa Reddy), umesh555@yahoo.co.uk (U. Kadam), dr.zubarev.alexander@gmail.com (A. Zubarev), zhengjie.lim@icloud.com (Z. Lim), c.anstey@griffith.edu.au (C. Anstey), biharishailesh@gmail.com (S. Bihari), drjyhaji@gmail.com (J. Haji), Jinghangluo@hotmail.com (J. Luo), smsaikatmitra1@gmail.com (S. Mitra), Ram_ramanathan@nuhs.edu.sg (K. Ramanathan), rrarvind@hotmail.com (A. Rajamani), frubulotta@hotmail.com (F. Rubulotta), erik.svensk@rvn.se (E. Svensk), Kiran.shekar@health.qld.gov.au (K. Shekar).

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HCW infection control guidelines during the severe acute respiratory syndrome coronavirus 2 pandemic and may also provide a framework for future guideline development.

1. Introduction

The novel coronavirus disease 2019 (COVID-19) pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has infected more than 175 million worldwide, with 3.79 million confirmed deaths as of June 14th 2021.[1] This pandemic has been severely burdening and outstripping the healthcare system capacities in many parts of the world.[2] A significant proportion of the infections recorded during the global pandemic have occurred in healthcare workers (HCWs).[3–5] It is estimated that more than 19,000 cases in the United States of America and more than 150,000 cases in Europe have been reported,[4,6–9] and they were at nearly three times the risk of infection.[10] As of August 2020, more than 2500 HCWs have died,[3] with that number likely to be a lot higher. Although the reasons may be multifactorial, it is not unreasonable to speculate that variable personal protective equipment (PPE) preparedness may have played a significant role in the HCW infection rate.[11] Prevention of exposure to the virus is the cornerstone of safe practice for HCWs involved in the care of SARS-CoV-2–infected hospitalised patients with COVID-19. This can be achieved by engineering solutions that are designed to minimise the risk of exposure, by building administrative processes that alter work practices, and through optimal use of PPE. Risk of contracting COVID-19 increases in the absence of effective PPE, suboptimal training in the correct use of PPE, and reusing or fashioning own PPE out of inappropriate materials.[11–17] Although the PPE production and practices for managing patients with COVID-19 have improved since the start of the pandemic,[18–21] concerns still exist amongst HCWs about the overall effectiveness of PPE provided by organisations owing to reports of PPE shortage emerging from multiple locations.[22–24] This is particularly relevant when health services are experiencing a state of surge with a rapid increase in hospitalised patients with COVID-19.

The COVID-19 pandemic has resulted in health systems and HCWs rapidly adopting various infection control strategies such as engineering, administrative, and PPE solutions to create a safe work environment and protect HCWs. Well-designed infection control guidelines based on available evidence, previous experience, and expert opinion can play a significant role in expedited reorganisation of the healthcare services, creating a safe work environment. Soon after the COVID-19 outbreak in Wuhan happened, the first PPE guideline, based on the World Health Organization (WHO) rapid advice guideline development methods, was released.[25] This guideline strongly recommended appropriate protection for all HCWs caring for patients with COVID-19 illness.[25] Various guidelines have since been published in quick succession owing to the need for direction in these uncertain times,[26] with many presenting conflicting information and many of the safety aspects not addressed in many of those guidelines.

HCW infection rates vary between countries, and the reasons behind this are probably multifactorial and are not entirely clear. Robust specific guidelines on SARS-CoV-2 infection control measures in healthcare facilities can help ensure high standards of patients' and HCWs' safety in line with the best available evidence on clinical care and cost-effectiveness. However, developing universal international infection control standards may be challenging and not always possible, given the disparities in socioeconomic conditions and healthcare infrastructure around the world. This may be reflected in the recommendations made in the published infection control guidelines in the early phase of the pandemic. Therefore, we aimed to develop a new consensus-based tool for appraisal guidelines on COVID-19 infection control in healthcare facilities that could be applicable for not only the COVID-19 pandemic but also any other pandemic in the future. Also, we aimed to validate the tool by testing it on various international and national, generic, and specialty-specific guidelines available at the time that address the issue.

2. Methods

As this work involved appraisal of publicly available guidelines, the Prince Charles Hospital Human Research Ethics Committee exempted this work from the ethics review process. A p-value of 0.05 was used to indicate statistical significance.

2.1. Development of a PPE guideline appraisal tool

2.1.1. The Delphi panel

The purpose of the Delphi panel was to reach a consensus on the guideline appraisal tool.[27] The panel included 84 participants (that also included 17 authors, Supplementary Table 1) and comprised medical managers; intensive care specialists; anaesthetists; infectious disease specialists; intensive care nurses and educators; infection control nurses; emergency, respiratory, and general physicians; surgeons (including ear nose and throat specialists and dentists); general practitioners; hospital executives; junior doctors; patient services assistants; and data managers. The details of the Delphi process are summarised in Fig. 1. Input from the panel was obtained using a three-step process. Each step comprised a web-based survey, the results of which were discussed in web-based meetings, followed by real-time polling of participants of the web meeting.

2.1.2. Delphi tool construction and reduction of the appraisal tool

We adapted the Delphi tool based on the Appraisal of Guidelines for REsearch & Evaluation (AGREE) clinical guidelines appraisal tool.[28,29] Using a modified Delphi process, we developed an initial survey after literature review and web-based discussions between authors. Authors participated in Delphi 1 survey and collaborators were invited to participate in Delphi 2 and 3 surveys. The round 1 Delphi survey questionnaire had seven domains with 85 items (Supplementary Table 1). The Delphi round 1 expected the respondents to mark one response out of “very important”, “somewhat important”, and “not important”. Based on the respondents' feedback, a refined round 2 survey with eight domains and 82 items was constructed (Supplementary Table 2). In Delphi round 2, the panel members were requested to mark the items on a two-point Likert scale, either as “important” or “not important”. After the second round, the survey was refined to six domains comprising 40 items. In round 3, for each of the six domains, participants were asked to rate the importance of assessing the domains in infection control guidelines using a seven-point Likert scale: 1 = strongly disagree, 2 = disagree, 3 = mildly disagree, 4 = neutral, 5 = mildly agree, 6 = agree, and 7 = strongly agree. Participants were explicitly instructed to evaluate the general concept of each domain. We did not offer any particular instrument used to measure these domains (Fig. 1). We analysed the results of the third round for agreement and degree of consensus. Only data for participants who completed both rounds were included in the results. The consensus was defined as a minimum average score of 5.25 (75%), meaning that the Delphi process would continue until at least 75% of the panel agreed a component should be included in the final tool.[30]

2.2. Validation of the developed PPE Guideline appraisal tool

We conducted a literature search using Pubmed, Embase, Web of Science, The Cochrane Central Register of Controlled Trials (CENTRAL), and CINAHL using the keywords "COVID-19" and "Guidelines" or "Recommendations" in the title between December 1st, 2019 and April 30th, 2020 which identified 33 and 59 articles, respectively (Supplementary Fig. 1). National COVID-19–specific guidelines that were not published in medical journals were found on the internet using Google and Bing search engines or obtained from the authors' professional contacts in these countries by personal correspondence. There were no language restrictions. Google translator was used to translate non-English guidelines. All guidelines published in foreign languages were translated to English by the survey participants. After a thorough selection process, we chose to appraise 40 guidelines published between December 1st, 2019 and April 30th, 2020 (Table 1): This included four international guidelines (G24 and G39, both WHO Guidelines; G27, European Centre for disease prevention and control; and G36, European International Liaison Committee for Resuscitation) and 23 national guidelines from each of high-income (n = 9, G1-G9), upper-middle (n = 4, G10-13), lower-middle (n = 6, G14-G18, G22), and low-income (n = 4, G19-12, G23) countries. The selection of national guidelines was primarily based on the country classification by gross national income (GNI) per capita levels.[31] Besides, specialty-specific (n = 8, G25-G32; emergency, critical care, and anaesthesia) and procedure-specific (n = 8, G33-G40; intubation, cardiopulmonary resuscitation, and handling of the deceased) guidelines were also included. Guidelines were allocated for appraisal to nine reviewers who were all experienced clinicians and frontline COVID-19 HCWs. The allocation of guidelines was random, regardless of the reviewers' background or preferences; however, reliable blinding was not feasible for the study. Each of the 40 guidelines was independently appraised by two reviewers, except the WHO guideline, which was appraised by five reviewers. The list and references of the 40 guidelines are provided in the supplementary document.

2.3. Statistical analysis

The differences in the Likert scores assigned by the assessors for each of the six domains were recorded for each of the 40 guidelines included in the final analysis. Guidelines (1–23) were tested first using clustering by the domains (1–6) and second using clustering by guideline type (25–40; specialty-specific and procedure-specific). Guideline 24 promulgated by the WHO was treated separately in both cases as it was graded by five assessors. Descriptive statistics for normally distributed data were presented using the mean and standard deviation, while median and interquartile range (IQR) were used to describe non-normally

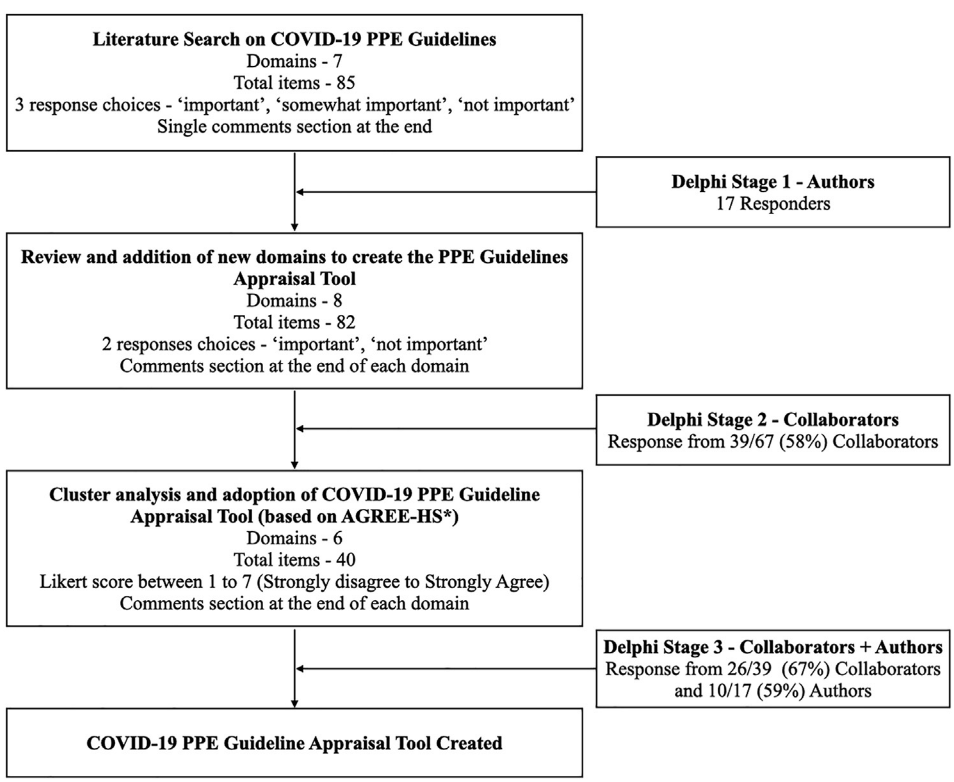

Figure 1. Flowchart of the Delphi survey showing the number of participants and the number of tools and domains from stages 1–3. Collaborators were invited to participate in Delphi 2 and 3 surveys. Thirty-nine of 67 (58%) participants invited for Delphi 2 completed the survey. Delphi 3 survey was sent to those 39 collaborators who completed Delphi 2 along with the authors of the study. Twenty-six of 39 (67%) collaborators and 10 of 17 (59%) authors completed Delphi 3 survey. COVID-19, coronavirus disease 2019; PPE, personal protective equipment.

distributed data. Dichotomous and categorical data were described using frequencies and percentages. Normality was assessed using the Shapiro–Wilk test. The Likert scores of each GNI group were normally distributed and illustrated as mean and 95% confidence interval. Binary comparisons were analysed using either a standard t-test for normally distributed data or Wilcoxon's rank-sum test for non-normal data. If the data were paired, the appropriate paired tests were used. Group comparisons for categorical data were analysed using the Kruskal–Wallis H test. General correlation and monotonicity were analysed using Spearman's rho (ρ), and inter-rater reliability was analysed using Cronbach's alpha (ρ_T). We used a prespecified score of >0.70 for Cronbach's alpha to demonstrate a good internal construct validity for using this appraisal tool. The level of significance was set at $p = 0.05$ throughout. STATA™ (version 15.1) was used for all analyses.

3. Results

3.1. The Delphi process

After the first round of survey, the Delphi panel members were invited to participate in the web-based survey rounds 2 and 3 that were circulated 3 days apart (Fig. 1). Thirty-nine of 67 (58%) participants who completed round 2 were invited to participate in round 3. Round 3 was completed by 36 of 56 (64.3%) of the panel members. The demographics of the participants in the Delphi

Table 1
The domains that should feature in an ideal infection control guideline as recommended by the Delphi panel.

Domains		Checklist
Domain 1: General characteristics for infection control		
1.	Guideline specific to COVID-19	❍
2.	Targeted at broad range of healthcare workers	❍
3.	Guideline based on robust evidence/best evidence where available	❍
4.	Layout of document (clarity, use of tables, animation, pictures)	❍
5.	Guidelines must be easy to follow	❍
Domain 2: Engineering recommendations for infection control		
1.	Guideline should recommend dedicated areas for safe patient care within the hospital	❍
2.	Guideline recommends PPE in context of these areas of care	❍
3.	Guidelines should discuss isolation rooms (e.g., being negative pressure, negative flow, or positive pressure)	❍
4.	Provides recommendations in relation on appropriate areas for performing AGPs	❍
5.	Dedicated and separated areas for donning and doffing	❍
Domain 3: PPE required for different clinical situations		
1.	Equipment specific for droplet precautions	❍
2.	Equipment for performing aerosol-generating procedures (AGPs)	❍
3.	Equipment specific for emergency situations (MET, code blue, cardiac arrest)	❍
4.	Equipment specific for intrahospital transfer	❍
5.	Equipment specific for interhospital transfer	❍
Administrative aspects of infection control		
Domain 4: PPE required for AGPs		
1.	Hand hygiene	❍
2.	Recommends regular training for donning/doffing	❍
3.	N95/P2 Fit test	❍
4.	Buddy system always present	❍
5.	N95/P2 Fit check	❍
6.	Recommends regular training for PPE use for AGPs	❍
7.	Clinical disposal for doffed PPE (biohazard waste)	❍
8.	Recommends training for cleaners	❍
9.	Minimum mandatory use of PPE	❍
10.	Duration of use of a single PPE	❍
11.	Prioritisation of PPE for nonventilated patients (on HFNO/NIV)	❍
12.	Prioritisation of PPE for airborne precaution	❍
13.	Prioritisation of PPE for AGPs	❍
14.	Prioritisation of PPE for mechanically ventilated patients	❍
15.	Recommendations provided for PPE reuse	❍
16.	Recommendations on how to sterilise PPE prior to reuse of N95 and/or face shield	❍
Domain 5: Minimum standards of PPE, prioritisation, and recommendations for reuse and sterilisation		
1.	Minimum mandatory use of PPE	❍
2.	Duration of use of a single PPE	❍
3.	Prioritisation of PPE for nonventilated patients (on HFNO/NIV)	❍
4.	Prioritisation of PPE for airborne precaution	❍
5.	Prioritisation of PPE for AGPs	❍
6.	Prioritisation of PPE for mechanically ventilated patients	❍
7.	Recommendations provided for PPE reuse	❍
8.	Recommendations on how to sterilise PPE prior to reuse of N95 and/or face shield	❍
Domain 6: Metrics for staff safety and wellbeing		
1.	Incident reporting systems for breaches in PPE/infection control	❍
2.	Postexposure management	❍
3.	Psychological health support and wellbeing for all essential staff and healthcare workers with the care and management of patients with COVID-19	❍
4.	Staffing and fatigue policies	❍
5.	Staff amenities meals, rest areas	❍
6.	Recommendations for healthcare workers at high risk	❍
7.	Accommodation for staff on active COVID duty to avoid going home to family	❍
8.	Length of COVID duty in each shift (4/6/12 h)	❍
9.	Guidance on post-COVID duty/shift precautions	❍

COVID-19: coronavirus disease 2019; MET: medical emergency team; AGP: aerosol-generating procedure; PPE: personal protective equipment; HFNO: high-flow nasal oxygenation; NIV: noninvasive ventilation.

consensus process are presented in Supplementary Table 3. The round 3 scores for each of the six domains are summarised in Supplementary Table 4. The breakdown of individual domain scores for round 3 is presented in Supplementary Table 5. The overall consensus was achieved with the mean scores ≥5.25 out of 7 (≥75%) for all items in the six domains, and three Delphi rounds were sufficient to reach this consensus. The Delphi panel recommended an ideal infection control guideline should encompass six domains: general characteristics (domain 1), engineering recommendations (domain 2), PPE use (domain 3), and administrative aspects (domain 4-6) of infection control (Table 1).

3.2. Guideline appraisal

The countries from which the guidelines were selected for appraisal based on the GNI per capita, with their corresponding confirmed cases and total deaths and transmission classification based on WHO situation report,[32] are summarised in Supplementary Tables 6 and 7. There was a significant difference in scores for domain 4 ($p = 0.047$). The Kruskal–Wallis H test p-values for the five reviewers grading G24 (WHO) were 0.51, 0.25, 0.63, and 0.88 respectively, while domains 5 and 6 were significantly different ($p = 0.009$ and $p = 0.002$, respectively). There was a good general correlation across all domains. Monotonicity analysis also revealed scores for the assessor pairs either rising or falling in unison. Finally, inter-rater agreement was excellent using Cronbach's alpha (Table 2).

Likert scores by domain for the national guidelines (G1 to G23) stratified based on the GNI are illustrated in Fig. 2. The median (IQR) scores for the national guidelines for each domain were as follows: domain 1 (general characteristics): 6.0 (5.0, 7.0), domain 2 (engineering recommendations): 5.5 (3.5, 6.5), domain 3 (PPE use for different procedures): 5.3 (2.5, 6.5), domain 4 PPE required for aerosol-generating procedures were 3.3 (1.3, 5.5), domain 5 (minimum standards of PPE, prioritisation, and recommendations for reuse and sterilisation) 2.5 (1.0, 5.5), and domain 6 (metrics for staff safety and wellbeing): 1.0 (1.0, 2.5). Domains 1, 2, and 3 scored significantly higher than domains 4, 5, and 6 ($p < 0.001$), with domain 6 scoring significantly lower than domains 1 to 5 ($p < 0.001$). The mean (standard deviation) scores by GNI per capita were as follows: high-income country: 4.10 (2.48); upper-middle-income country: 3.91 (2.14); lower-middle-income country: 2.85 (2.08), and low-income country: 4.07 (2.21). The overall mean Likert scores by GNI per capita for G1-23 were 3.80. The Likert scores for the high-, upper-middle-, and low-income groups were not significantly different, whilst the scores for the lower-middle-income group were significantly lower than the other three groups ($p < 0.001$, Supplementary Fig. 2).

Likert scores by domain for the specialty-specific and procedure-specific guidelines (25–40) are illustrated in Fig. 3. The median scores (IQRs) for the professional society and procedural guidelines for each domain were as follows: domain 1: 6.0 (5.0, 6.5), domain 2: 5.0 (2.5, 6.5), domain 3: 3.5 (1.0, 6.0), domain 4: 2.5 (1.0, 5.5), domain 5: 1.0 (1.0, 4.0), and domain 6: 1.0 (1.0, 2.0). Domains 1 and 2 scored significantly higher than domains 3 to 6 ($p < 0.001$), whilst domain 6 scored significantly lower than domains 1 to 5 ($p < 0.001$).

4. Discussion

This was the first study to develop a universal COVID-19 infection control–specific guideline appraisal tool using the Delphi consensus process. This guideline appraisal tool was tested and validated against 40 guidelines. We observed that the appraisal tool was robust, was easy to use, and performed well across all domains with an excellent inter-rater agreement. We observed that all guidelines performed relatively better in domains 1–3 than in domains 4–6. All but one of the 40 guidelines scored poorly in these domains 4–6. We recommend that any new COVID-19–related infection control guideline that is drafted should focus specifically on attending domains 4–6. We believe that this tool may enable health systems to adopt high-quality HCW infection control guidelines during the SARS-CoV-2 pandemic and may also provide a framework for future guideline development.

A PPE guideline appraisal tool was developed and validated utilising a validated Delphi consensus-building process.[33] The diverse multidisciplinary Delphi panel allowed for the development of a robust generalisable tool. By providing the numerical Likert scale and a high score consensus for the questions to be retained,[34,35] we developed a tool that was objective. The consensus was achieved across all domains despite the diversity of the panel, making both the process and tool robust. Discussion and exploration of differences were an important part of this process, and this was served well by the iterative methodology inherent in the Delphi process.[27] The final six domains created within the tool through the Delphi process consisted of both general and specific recommendations about the use of strategies to minimise the risk of HCW infections. The tool was then tested for its reliability and validity by appraising 40 varying international/national, specialty-

Table 2
Agreement scores (median, IQR) between domains with reliability coefficients. Results indicate very good agreement between the assessors. The Delphi system used was reliable and robust with excellent inter-rater agreement.

Domain	Assessor 1	Assessor 2	p-value	Spearman's rho (ρ)	Cronbach's alpha (ρ_T)
1	6 (5, 7)	6 (5, 7)	0.49	0.60	0.78
2	5 (4, 7)	5 (2, 7)	0.21	0.71	0.84
3	5 (1, 7)	4 (1, 7)	0.20	0.73	0.86
4	4 (1, 7)	3 (1, 6)	**0.047**	0.73	0.85
5	1 (1, 5)	2 (1, 4)	0.90	0.72	0.83
6	1 (1, 1)	1 (1, 1)	0.97	0.65	0.86
All				0.79	0.88

Spearman's rho assesses monotonicity to assess whether the two variables rise and fall together. Cronbach's alpha is a commonly used score that measures agreement between the two variables.
Domain 1: General characteristics for infection control.
Domain 2: Engineering recommendations for infection control.
Domain 3: PPE required for different clinical situations.
Domain 4: PPE required for AGPs.
Domain 5: Minimum standards of PPE, prioritisation, and recommendations for reuse and sterilisation.
Domain 6: Metrics for staff safety and wellbeing.
AGP: aerosol-generating procedure; PPE: personal protective equipment; IQR: interquartile range.

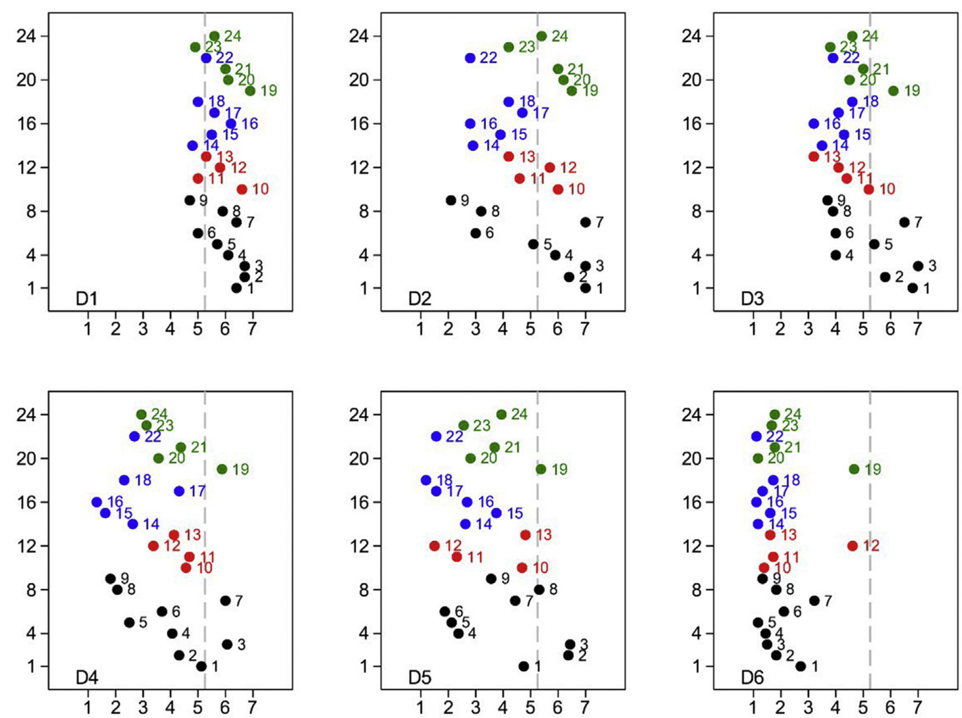

Figure 2. Median Likert scores by domain (national guidelines 1 to 24 inclusive): Black: high-income country; red: high-middle-income country; blue: low-middle-income country; green: low-income country. Domains D1 to D6 are identified on each panel. The vertical line at 5.25 indicates the median score for all guidelines. (domain 1: general characteristics for infection control; domain 2: engineering recommendations for infection control; domain 3: PPE required for different clinical situations; domain 4: PPE required for AGPs; domain 5: minimum standards of PPE, prioritisation, and recommendations for reuse and sterilisation; domain 6: metrics for staff safety and wellbeing). PPE, personal protective equipment; AGPs, aerosol-generating procedures.

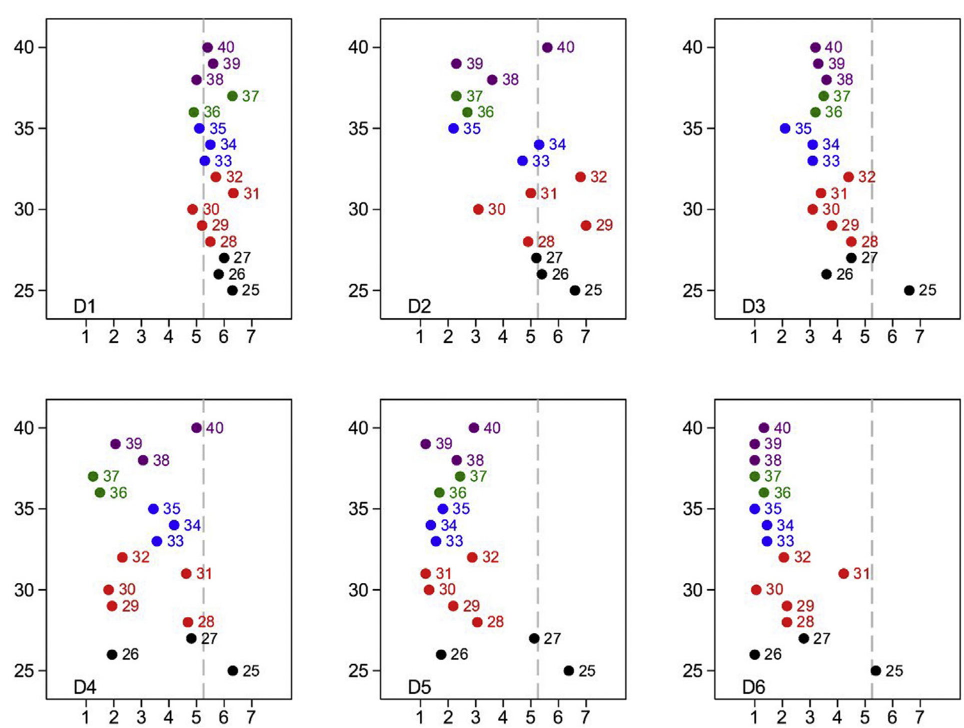

Figure 3. Median Likert scores by domain (societal guidelines 25 to 40 inclusive). Black: intensive care unit society guidelines; red: anaesthesia society guidelines; blue: intubation procedural guidelines; green: CPR procedural guidelines; purple: handling of deceased guidelines. Domains D1 to D6 are identified on each panel. The vertical line at 5.25 indicates the median score for all guidelines (domain 1: general characteristics for infection control; domain 2: engineering recommendations for infection control; domain 3: PPE required for different clinical situations; domain 4: PPE required for AGPs; domain 5: minimum standards of PPE, prioritisation, and recommendations for reuse and sterilisation; domain 6: metrics for staff safety and wellbeing). PPE, personal protective equipment; AGPs, aerosol-generating procedures; CPR, cardiopulmonary resuscitation.

specific, and procedure-specific guidelines. Being the first of its kind, there were no pre-existing tools for comparison and to assess for the general validity (construct) of this measurement tool.[36] Involving a diverse expert panel with a wide range of expertise enhanced its content validity.[36] A Cronbach's α score of >0.70 demonstrated very good internal construct validity for using this appraisal tool. Sufficient details, presented as supplementary material, can be used to replicate this tool and be evaluated independently.

A range of published international and national infection control guidelines was utilised for validation of the tool. The WHO guidelines have been widely adopted by many low- and middle-income countries that have not published dedicated national guidelines and were an obvious inclusion. Similarly, including published guidelines from countries with different GNI strata added to the strength of the study. Infection control practices and hence guidelines may significantly vary between countries based on socioeconomic status and available resources. Besides, including appraising guidelines from specialty-specific and procedure-specific guidelines was relevant to ensure these guidelines provided engineering, administrative, and PPE-specific recommendations to HCWs at risk.

The appraisal tool performed well across all domains. All included guidelines scored relatively better in domains 1–3 than in domains 4–6. Domain 1 of the appraisal tool focused on the “demographic” of any guideline (i.e., whether it was specific to COVID-19, whether it targeted relevant HCWs, and if it was based on robust evidence or expert consensus, length, and layout, and ease of reading/interpreting the guideline). We consider parsimony to be important in a time of information overload and an oversupply of guidelines. Domain 2 focused on the recommendations on engineering solutions that are fundamental to infection control practices. This is especially important given that aerosol and fomite transmission of SARS-CoV-2 is plausible since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days.[37] Domain 3 was PPE-specific that was required for appropriate HCWs' protection in different clinical situations. Domains 4–6 were based on recommendations on administrative solutions for infection control that included PPE training, fit testing of masks, efficient PPE use, PPE reuse, PPE disposal, etc. In particular, domain 6 included recommendations that promote a culture of staff safety, risk and adverse event reporting, and staff support. Surprisingly, this domain was the most neglected one in most guidelines. We postulate that this could be because of a lack of the resources, incentives, and facilities that can be provided to HCWs during a surge. It may also be due to the lack of advocacy on behalf of HCWs. Equally, a culture of safety is built over time and ideally should be embedded in clinical practice even outside a pandemic and may not be implemented de novo at the height of the pandemic. Infection control goes beyond the use of PPE. While PPE provides immediate physical and psychological safety to the HCWs, engineering and administrative solutions help build an enduring culture of safety in health systems. Therefore, improvements in these domains are critical to the wellbeing of the HCWs. None of the national guidelines had a score >5.25 in any of the studied domains. This finding was no different in specialty-specific and procedure-specific guidelines, with only one guideline discussing this in adequate detail. Therefore, we identify domains 4–6 as areas where significant gains can be made across all guidelines assessed.

Our primary intention was not to compare the guidelines but to validate the guideline appraisal tool. In addition to its utility as a tool for PPE guideline assessment, we believe this tool can provide a reliable framework while writing new guidelines. Although guidelines evolve over time as new evidence becomes available, the domains listed in this tool that is based on the key principle of infection control are likely to stay relevant. A well-written guideline that performs well applying our appraisal tool can still be poorly implemented on the ground. Thus, the quality of any PPE guideline may in itself does not guarantee safety, and this calls for the development of quality metrics that help track gaps in the implementation of guidelines and quality of infection control practices including PPE and HCW infection rates over time.

The strengths of this study include being the first of a kind where the authors developed and validated a guideline appraisal tool by appraising 40 different infection control guidelines from countries with varying GNI, specialty-specific, and procedure-specific guidelines. The experienced Delphi panel comprised HCWs from junior and senior doctors, nurses, hospital executives, and patient service assistants. Therefore, all aspects of infection control were duly considered. However, there are a few limitations that need to be acknowledged. The authors only reviewed the infection control guidelines in the early phase of the pandemic, where there were significant PPE shortages and SARS-CoV-2 was believed to be droplet spread. The WHO revised that to aerosol spread in July 2020 after an open letter from 239 scientists from 32 countries urging the WHO and other bodies to address the potential for airborne transmission of the coronavirus.[38] The nature of the consensus-building process used is such that there is a possibility of a key infection control guideline component not be included in the final tool, because either none of the panelists suggested their inclusion in round 1 or the guidelines may have got discarded owing to lack of consensus in subsequent rounds. Lack of broader global representation in the panel may have led to a key infection control measure not being included in the tool. Reassuringly, we did not come across any such measures our tool may have missed while appraising the guidelines. Furthermore, with the ongoing pandemic surge in many parts of the world, there has been increased production of PPE and improved PPE practices since. It may be perceived as a selection bias of only appraising a few guidelines (40 of 92 at that time), but the authors appraised all publicly available guidelines and comprehensive search measures were undertaken to obtain all available guidelines. Besides, some guidelines were not in English, and a Google translator was used, which could have limited the validity of the results. However, Google translator uses robust and efficient technology with scientific validity.[39,40] Furthermore, more than 50% of the participants largely from a critical care workforce who evaluated a range of guidelines must be acknowledged. Although there was a dropout of the Delphi panel members between surveys 2 and 3, we believe this would not have influenced the overall consensus process. Finally, although the data on their actual experience in managing patients with COVID-19 were not available, most of the Delphi panel members were from Australia and their experience would have been less than HCWs' in other parts of the world who had faced more significant disease burden; this may potentially limit generalisability. However, many of the authors who participated in Delphi surveys 1 and 3 were from various countries such as the UK, Sweden, Singapore, and India. Many of these countries had significant caseloads in the early phase of the pandemic. More research is needed to explore the gaps in guideline implementation and to explore the relationship between the quality of infection control guidelines and HCW infection risks during a pandemic.

5. Conclusion

We developed and validated guideline appraisal tools using a rigorous process. The tool performed well when applied across several international, national, specialty-specific, and procedure-specific guidelines and helps identify the strengths and weaknesses of each guideline.

Author Contributors

A.S. and K.S. conceived the project idea. The Delphi steering committee comprised A.S., M.R., U.K., A.Z., Z.L., and K.S. The literature review was conducted by A.S., M.R., A.Z., Z.L., S.M., U.K., and K.S. to create the domains and items for Delphi round 1. A.S., M.S., A.Z., M.R., U.K., and E.S. distributed the Delphi round 2 and 3 surveys and discussed results to reduce and refine the final tool. The 40 guidelines were randomly allocated to the reviewers by A.Z. These guidelines were reviewed by A.S., A.Z., A.R., J.H., J.L., M.R., S.M., U.K., and Z.L. The results were collated by A.Z. and A.S. C.A. conducted the statistical analysis. A.S. and K.S. analysed the data and wrote the initial drafts of the manuscript with inputs from M.R., A.Z., and U.K. A.S., A.Z., C.A., and S.M. created the tables and figures. A.S. and K.S. finalised the manuscript. All authors critically reviewed the manuscript and approved the final version before submission.

CRediT authorship contribution statement

Ashwin Subramaniam: Conceptualisation, Methodology, Data curation, Supervision, Project administration, Formal analysis, Writing – original draft, Writing – review and editing. **Mallikarjuna Reddy**: Methodology, Data curation, Software, Writing – review and editing. **Umesh Kadam**: Methodology, Data curation, Software, Writing – review and editing. **Alexander Zubarev**: Data curation, Formal analysis, Writing – review and editing. **Zheng Lim**: Data curation, Writing – review and editing. **Chris Anstey**: Data curation, Formal analysis, Software, Writing – review and editing. **Shailesh Bihari**: Writing – review and editing. **Jumana Haji**: Data curation, Writing – review and editing. **Jinghang Luo**: Data curation, Writing – review and editing. **Saikat Mitra**: Data curation, Writing – review and editing. **Arvind Rajamani**: Data curation, Writing – review and editing. **Kollengode Ramanathan**: Writing – review and editing. **Francesca Rubulotta**: Writing – review and editing. **Erik Svensk**: Writing – review and editing. **Kiran Shekar**: Conceptualisation, Methodology, Supervision, Project administration, Formal analysis, Writing – original draft, Writing – review and editing.

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Appendix A. Supplementary data

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