

End-user acceptability of personal protective equipment disinfection for potential reuse: a survey of health-care workers in Aotearoa New Zealand

Cervantée E K Wild, Hailey Wells, Nicolene Coetzee, Cameron C Grant, Trudy A Sullivan, José G B Derraik, Yvonne C Anderson



Summary

Background The COVID-19 pandemic has highlighted personal protective equipment (PPE) supply, distribution, and disposal issues worldwide. Calls to conserve PPE stocks and increase supply resulted in the rapid development of potential disinfection methods, with the possibility of improvements in medical waste reduction. However, how receptive health-care workers are to PPE reuse remains unknown. We aimed to examine the views of health-care workers who used PPE during the first COVID-19 wave in Aotearoa New Zealand, in relation to acceptability of PPE disinfection and reuse.

Methods In this multi-methods survey, health-care workers in New Zealand, were invited via a multimodal recruitment strategy to complete a survey regarding use of PPE during the first COVID-19 wave. Gender question options were male, female, gender diverse, or prefer not to say. Demographic differences in self-reported PPE reuse and acceptability were examined. The survey included closed (single-response, multi-response, ranking, and Likert-scale questions) and open-text questions. Any open-text comments were analysed with thematic analysis. The survey was built and deployed using Qualtrics software.

Findings 1411 health-care workers completed the survey between Oct 7 and Nov 30, 2020. 1397 participants had gender data available (1140 [82%] female and 257 [18%] male) and 995 (74%) of 1347 were of New Zealand European ethnicity. PPE reuse was common and reported by 628 (45%) of the 1411 participants, with 396 (63%) of the 628 reporting reusing PPE multiple times in 1 day. Acceptability of the concept of PPE disinfection for potential reuse was high overall (1196 [85%] of 1411) but varied depending on the type of PPE. Thematic analysis confirmed that PPE reuse was already occurring and respondents recognised the potential benefits of reduced medical wastage and increased PPE supply. Important caveats for consideration included the availability of scientific evidence, level of negotiated risk, and trust in the organisation undertaking PPE disinfection, with clear communication about decontamination processes being crucial to acceptability.

Interpretation PPE reuse occurred frequently during the first wave of COVID-19 in New Zealand. Although support for the disinfection of PPE for reuse was high, the success of any future programmes to reuse PPE will require meaningful engagement and clear communication with health-care workers. Further research into PPE disinfection safety and logistics is warranted, alongside the development of standard operating procedures and clearly communicated policies for the end user, should this more sustainable health-care practice be planned for adoption in certain settings.

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Introduction

The COVID-19 pandemic has added considerable pressure to global health systems, requiring large volumes of personal protective equipment (PPE) to mitigate the high risk of SARS-CoV-2 infection in health-care workers and subsequent virus transmission to patients.¹ Globally, there have been PPE shortages due to supply chain and distribution issues, closed borders and reduced freight, PPE theft, and stock not fit for use.^{2–4} Even as supply concerns have abated, medical waste has increased substantially and has exacerbated already strained waste management systems; an initial report from WHO suggests that much of the PPE shipped to support countries' urgent COVID-19 response needs was sent to landfill.⁵

Additionally, health-care workers have turned to alternative, makeshift means of protection when PPE stocks are low.⁴ PPE includes surgical masks, eye protection (glasses, goggles, face shields), gloves, gowns, and filtering facepiece respirators (FFRs; also known as N95s). PPE is recommended for single use except in extreme shortages or emergency situations; several organisations, including WHO, provided guidance for extended wear and reuse after reprocessing.^{3,6,7} Calls to conserve PPE stocks,⁸ reduce medical wastage,⁵ and increase front-line supply have led to the rapid development of potential disinfection methods, including ultraviolet irradiation, dry and moist heat, and vaporised hydrogen peroxide.^{7,9–12} The eventual increase in PPE supply led the US Food and Drug

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Department of Paediatrics:
Child and Youth Health, Faculty
of Medical and Health Sciences,
University of Auckland,
Auckland, New Zealand
(C E K Wild PhD, H Wells MNurs,
N Coetzee PhD,
Prof C C Grant PhD,
J G B Derraik PhD,
Y C Anderson PhD); Nuffield
Department of Primary Care
Health Sciences, University of
Oxford, Oxford, UK (C E K Wild);
General Paediatrics, Starship
Children's Hospital, Auckland,
New Zealand (Prof C C Grant);
Department of Preventive and
Social Medicine, University of
Otago, Dunedin, New Zealand
(T A Sullivan PhD); enAble
Institute, Faculty of Health
Sciences, Curtin University,
Bentley, WA, Australia
(Y C Anderson); Telethon Kids
Institute, Perth Children's
Hospital, Nedlands, WA,
Australia (Y C Anderson);
Community Health, Child and
Adolescent Health Service,
Perth, WA, Australia
(Y C Anderson)

Correspondence to:
Dr Yvonne Anderson, enAble
Institute, Faculty of Health
Sciences, Curtin University,
Bentley, WA 6102, Australia
yvonne.anderson@curtin.edu.
au

Research in context

Evidence before this study

Calls to conserve personal protective equipment (PPE) stocks and increase front line supply during the COVID-19 pandemic led to rapid development of various disinfection methods. While current standards do not recommend reusing PPE, global institutions have released guidelines for reuse during shortages. However, PPE disinfection for potential reuse must be acceptable to health-care workers. Before undertaking this study, we identified one study of health-care workers' perspectives on implementation of decontamination methods, indicating that trust in the process is key to acceptability. To the best of our knowledge, there were no comprehensive or nationwide studies previously undertaken on this subject.

Added value of this study

There is conditional support for PPE disinfection among health-care workers in Aotearoa New Zealand, based on the desire to reduce medical wastage and increase PPE supply. Acceptability of PPE disinfection is dependent on the availability of scientific

evidence relating to the safety of disinfection methods, and on the level of negotiated risk and workers' trust in the organisation undertaking PPE disinfection. Clear communication relating to any disinfection process is paramount.

Implications of all the available evidence

PPE reuse has been common during the pandemic response in New Zealand, often in the absence of guidelines for such practices. PPE disinfection and reuse is potentially acceptable to health-care workers as an ongoing and more sustainable health practice; however, there is a need for clear policies and procedures relating to any PPE disinfection methods and for good communication of the safety evidence to health-care professionals. While safe PPE disinfection and reuse programmes might help to reduce the environmental footprint of health-care services, their development and success will depend on end-user acceptance, as well as trust in the organisations implementing any reuse policy.

Administration to revoke all issued authorisations for PPE disinfection and reuse.⁷

Nonetheless, the practice of disinfecting and reusing PPE remains important in a highly interconnected world with marked socioeconomic disparities between countries, where many nations are still likely to face inadequate PPE supply due to economic factors or geographical isolation. In the case of Aotearoa New Zealand (henceforth referred to as New Zealand), the COVID-19 pandemic exposed the country's vulnerability to disruptions in the global supply chain.¹³ Importantly, the pandemic also resulted in a marked increase in the manufacture and wear of single-use PPE, with one study estimating that during the first COVID-19 surge as many as 129 billion face masks and 65 billion gloves were being used worldwide every month.¹⁴ The inevitable result has been a marked increase in the contribution of single-use PPE to the plastic pollution in terrestrial and aquatic ecosystems, further highlighting the need to reduce the volume of single-use PPE being produced and subsequently discarded.¹⁵

However, contemporary research identified health-care workers' lack of trust in disinfection methods as potential barriers to reuse,¹⁶ with changing guidance causing justified concern.¹⁷ A study of US health-care workers' perspectives showed wearing a decontaminated FFR was preferred over extended wear or no protection; however, trust in the decontamination methods was key.¹⁸ Solutions for PPE disinfection and reuse should be acceptable to end users. Therefore, this study aimed to describe the views, attitudes, and perceptions of health-care workers in New Zealand towards disinfection of PPE for potential reuse, and the circumstances in which this practice would be acceptable.

See Online for appendix

Methods

Study design and participants

New Zealand has previously been heralded as having one of the world's best responses to COVID-19.¹⁹ The country's first COVID-19 wave was from Feb 28 to June 8, 2020, with 1504 cases and 22 deaths.²⁰ New Zealand subsequently experienced 102 days without community transmission. This multi-methods study presents national survey results from front-line health-care workers in New Zealand who used PPE during the first COVID-19 wave. A multimodal recruitment strategy²¹ was used to maximise reach and potential response, including distribution of an email invitation through professional and representative organisation mailing lists, newsletters, social and collegial networks, study advertisements on organisation websites, social media, and word of mouth. Of note, several organisations declined to distribute the survey as they did not want to give the impression to their members that they supported PPE disinfection. Eligibility was self-selected on the basis of being a health-care worker who used PPE, as well as other front-line workers such as border control, fire service, and the police. Participants were offered the chance to win one of three NZD100 vouchers (winner's choice of grocery or petrol voucher). Ethics approval was obtained from the Auckland Health Research Ethics Committee (AH2640). Consent from each respondent was obtained through electronic agreement with a consent statement before proceeding to the survey.

Procedures

The anonymous online survey asked participants about acceptability of PPE disinfection for potential reuse, their PPE experiences, demographics, and COVID-19 infection status (appendix pp 7–9). Participants' views on PPE

disinfection for reuse are presented here in this Article. The survey included closed (single-response, multi-response, ranking, and Likert-scale questions) and open-text questions (extension, expansion, and general open questions).²² Ethnicity data was collected via self-report according to New Zealand Ministry of Health protocols (appendix pp 7–8).²³ Gender data were also self-reported (available options were male, female, gender diverse, prefer not to say). The survey was built and deployed using Qualtrics software (Qualtrics, Provo, UT, USA). Both computer and mobile versions were beta-tested for face validity but did not undergo further validation.

Statistical analysis

For cases in which a respondent recorded multiple ethnicities, data were categorised using prioritised output.²³ Categorical data were analysed using χ^2 tests or Fisher's exact tests. Ordinal data from Likert scales were analysed using a non-parametric Mann-Whitney U test, with group statistics reported as the median (IQR). All analyses were two-tailed, with statistical significance set at $p < 0.05$.

The qualitative data were analysed using thematic analysis²⁴ guided by the overarching question: "Is the concept of PPE disinfection for potential reuse acceptable to end-users?". The four survey questions that informed the qualitative analysis were expansion questions (eg, "Why/Why not?"), and answers to open-ended questions (eg, "Any other comments?") that pertained specifically to PPE disinfection. Data were inductively coded by both CEKW and NC using nVivo version 1.2 (QSR International, Doncaster, VIC, Australia), with discrepancies resolved in real time with discussion between the two investigators. CEKW then generated initial themes by identifying broader patterns among the codes and collating data under headings. Both CEKW and NC then reviewed the candidate themes against the dataset to check for viability. The themes were peer debriefed with YCA and refined into the final analyses. Quantitative data were analysed using SPSS (version 28; IBM Corp, Armonk, NY, USA).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Of the 1411 survey participants between Oct 7 and Nov 30, 2020, 1397 had available gender data, of which 1140 (82%) were female and 257 (18%) were male (table 1). All participants had available age data, and 400 (28%) were aged 55 years or older. 1347 participants had available ethnicity data and 995 (74%) were New Zealand European (table 1). Participants lived across New Zealand, with 1025 (76%) of 1346 from the North Island (appendix p 18). 73 (5%) of 1411 reported having contracted COVID-19 and

159 (11%) of 1411 reporting knowing a relative or friend who had contracted COVID-19. Total numbers of responses varied across survey questions. There were 257 incomplete survey entries.

Personally reusing PPE during the first wave was reported by 628 (45%) of the total 1411 respondents, with 396 (63%) of the 628 who reported personally reusing PPE citing multiple reuses in 1 day (table 2). Of the 334 participants who reported their organisation collected PPE for reuse, 246 (74%) thought there was a well communicated process relating to this practice. Personal PPE reuse was more common among younger participants (346 [52%] of 665 aged <45 years vs 282 [38%] of 746 aged ≥ 45 years; $p < 0.0001$) and those working in the private sector (266 [51%] of 524 vs 359 (41%) of 879 participants in the public sector; $p = 0.0003$).

Overall, 1196 (85%) of 1411 respondents indicated they would be comfortable reusing PPE after disinfection (table 3), with participants mostly comfortable with reuse after disinfection if there were supply shortages (903 [64%] of 1411). There was greater acceptance of reuse of disinfected eyewear (1120 [94%]) and face shields (1099 [92%]) than gowns (807 [67%]), FFRs (475 [40%]), and surgical masks (373 [31%]). However, there were marked differences in the acceptability of reused PPE for medical and nursing staff, especially regarding reused

	Number of participants (n=1411)
Gender	
Female	1140/1397 (82%)
Male	257/1397 (18%)
Ethnicity†	
New Zealand European	995/1347 (74%)
Asian	190/1347 (14%)
Māori	102/1347 (8%)
Other	60/1347 (4%)
Age group, years	
<35	366 (26%)
35–44	299 (21%)
45–54	346 (25%)
≥ 55	400 (28%)
Profession	
Medical	269 (19%)
Nursing	468 (33%)
Dental	86 (6%)
Allied health‡	486 (34%)
Other health§	102 (7%)

Data are n (%) or n/N (%). *Comparative national health workforce data not available. †Prioritised ethnicity classification.¹⁹ ‡Allied health included: ambulance officer, dental hygienist, dietitian, health-care assistant, midwife, optometrist, pharmacist, phlebotomist, physiotherapist, play specialist, podiatrist, psychologist, radiologist, social worker, speech and language therapist, and allied health professional not otherwise specified. §Other health included: health administration and management, cleaner, laboratory, orderly, research, public health, employee in sterile services, and technician.

Table 1: Demographic characteristics of 1411 survey respondents*

	Medical (n=269)	Nursing (n=468)	Dental (n=86)	Allied health (n=486)	Other health (n=102)	Total (n=1411)
Reuse of PPE						
Personally reused PPE	164 (61%)	182 (39%)	41 (48%)	198 (41%)	43 (42%)	628 (45%)
Reusing PPE items multiple times in 1 day*	92/164 (56%)	116/182 (64%)	22/41 (54%)	136/198 (69%)	30/43 (70%)	396/628 (63%)
Reusing PPE items multiple times over more than 1 day*	36/164 (22%)	26/182 (14%)	9/41 (22%)	24/198 (12%)	6/43 (14%)	101/628 (16%)
Other*†	4/164 (2%)	9/182 (5%)	2/41 (5%)	3/198 (2%)	3/43 (7%)	21/628 (3%)
Organisation collected PPE for reuse						
Yes	117 (43%)	124 (26%)	14 (16%)	57 (12%)	22 (22%)	334 (24%)
No	90 (33%)	235 (50%)	64 (74%)	289 (59%)	51 (50%)	729 (52%)
Do not know	62 (23%)	109 (23%)	8 (9%)	140 (29%)	29 (28%)	348 (25%)
Items of PPE collected by organisation*‡						
Filtering facepiece respirators	49/117 (42%)	32/124 (26%)	4/14 (29%)	20/57 (35%)	12/22 (55%)	117/334 (35%)
Surgical masks	18/117 (15%)	10/124 (8%)	2/14 (14%)	9/57 (16%)	1/22 (5%)	40/334 (12%)
Gowns	29/117 (25%)	28/124 (23%)	8/14 (57%)	13/57 (23%)	3/22 (14%)	81/334 (24%)
Face shields	80/117 (68%)	85/124 (69%)	10/14 (71%)	33/57 (58%)	13/22 (59%)	221/334 (66%)
Eyewear	83/117 (71%)	99/124 (80%)	10/14 (71%)	44/57 (77%)	10/22 (45%)	246/334 (74%)
Other§	2/117 (2%)	4/57 (7%)	..	6/334 (2%)
Well communicated rationale for collection‡						
Yes	85/117 (73%)	88/124 (71%)	14 (100%)	43/57 (75%)	16/22 (73%)	246/334 (74%)
No	25/117 (21%)	32/124 (26%)	..	10/57 (18%)	5/22 (23%)	72/334 (22%)
Do not know	7/117 (6%)	4/124 (3%)	..	4/57 (7%)	1/22 (5%)	16/334 (5%)
Data are n (%) or n/N (%). PPE=personal protective equipment. *Multiple responses possible, so totals add up to 100% or more. †“Other” responses given by participants included: reuse after a stand-down period, reuse if perception of low risk, reuse on a single patient, and reuse of specific items of PPE. ‡Percentages reported are of participants whose organisations collected PPE for reuse, by profession. §“Other” responses given by participants included gloves, other types of masks, and other garments.						
Table 2: Reuse of PPE during the first wave of the COVID-19 pandemic in New Zealand, by profession						

FFRs (161 [62%] of 261 vs 114 [29%] of 391; $p < 0.0001$), surgical masks (119 [46%] of 261 vs 77 [20%] of 391; $p < 0.0001$), and protective gowns (217 [83%] of 261 vs 220 [56%] of 391; $p < 0.0001$; table 3).

Younger age (597 [90%] of 665 participants <45 years vs 599 [80%] of 746 participants ≥ 45 years; $p < 0.0001$) and New Zealand European ethnicity (862 [87%] of 995 vs non-New Zealand European ethnicity, 275 [78%] of 352; $p = 0.0002$) were associated with slightly greater comfort with the concept of PPE reuse post disinfection. Comfort with PPE reuse was more common among health-care workers who reported receiving adequate PPE from their organisation than in those who did not (801 [87%] of 920 vs 336 [79%] of 427; $p < 0.0001$), and among those whose organisations collected PPE for reuse than in those who did not (305 [91%] of 334 vs 891 [83%] of 1077; $p = 0.0001$). Furthermore, participants comfortable with reusing PPE after disinfection reported higher trust scores in their organisations' ability to supply enough PPE (median 7 [IQR 5–9]) compared with those uncomfortable reusing disinfected PPE (median 6 [IQR 3–8]; $p < 0.0001$).

However, being comfortable or not with reusing disinfected PPE was not associated with reported COVID-19 infection history (COVID-19 history, 58 [79%] of 73 vs no COVID-19, 1138 [85%] of 1338; $p = 0.20$), the requirement to undertake aerosol-generating procedures (yes, 402 [85%] of 475 vs no, 730 [85%] of 863; $p = 0.98$), or

confidence in their organisations to provide necessary PPE in future COVID-19 waves (confidence, 567 [86%] of 660 vs not confident, 570 [83%] of 687; $p = 0.14$).

Scientific evidence of the efficacy of disinfection against key human pathogens was considered beneficial by 1214 (86%) of 1410 respondents (appendix p 19). Chain of identity (ie, receiving one's own disinfected PPE back) was “somewhat” important for 350 (25%) of 1411 respondents and “very” important for 464 (33%) respondents. 163 (12%) of 1411 were not prepared to invest any time to receive their own PPE back post disinfection, while 384 (27%) responded they were willing to invest 5 min per shift, with 137 (10%) willing to spend 30 min or more per shift (appendix p 19). Packaging preferences were mixed, with 433 (34%) of 1271 who answered this question preferring to receive their disinfected PPE wrapped in biodegradable plastic, and 199 (16%) with no preference. When asked whether new PPE is sterile, 640 (45%) of 1411 correctly answered “no”, with 521 (37%) answering “yes”, and 250 (18%) answering “don't know”.

The importance of medical waste reduction from single-use products, was “somewhat important” for 486 (35%) of 1411 and “very important” for 589 (42%) participants (appendix p 19).

Qualitative thematic analysis supported the quantitative findings, showing that, overall, the concept of PPE disinfection for reuse was acceptable for most participants

(panel 1). Each theme was supported by multiple participant comments from the survey. Italicised square brackets denote explanations of acronyms or abbreviations, or additional explanations or truncation of a quotation by the authors. Regular brackets were used by participants in their own responses. Recommendations based on these and the quantitative findings are presented in panel 2.

PPE reuse is already occurring using a range of methods. Participant comments indicated that PPE was already being reused with a range of disinfection methods. This was driven by both individuals and organisations with varying levels of scientific evidence:

“I used to reuse my surgical masks [...] I used to dry them under the direct sun and reuse them up to 3 days per mask. I believed that it could provide enough protection as long as the filter is not damaged, dried if it's used for own [use] only.”

Pharmacist, Asian, female

Participants also suggested that reusing PPE might be justified because of already established models and precedents in health care for reusing medical equipment after sterilisation or disinfection processes.

“Blood gets donated, scrubs get cleaned, transoesophageal transducers get sanitised, I think it's possible to create a system where PPE items are reused.”

Sonographer, New Zealand European, female

Health-care workers recognise multiple benefits to reusing disinfected PPE. Identified benefits of PPE disinfection for reuse included increased PPE supply and decreased medical wastage, with the caveat that personal safety of health-care workers was not compromised.

“We should shift our focus—if the data backs it up—to reusing and reprocessing items. It will improve waste and control stock levels.”

Nurse, New Zealand European, female

Specifically, the reduction of medical wastage was seen as crucially important:

“I think we are a wasteful society and we throw a lot of things away unnecessarily. If we can recycle safely then we should. We shouldn't be putting plastic into the ground any way.”

Occupational therapist, Māori, female

“I applaud any effort to reduce environmental waste and also environmental damage through manufacture and distribution of single use medical equipment. We, as a profession, need to wake up to the impact provision of healthcare has on the environment.”

General practitioner, New Zealand European, female

The relevance of continued sustainable practice in non-pandemic times was apparent, with one participant stating that “whatever we learn as a result of this should be applicable in non-Covid times”. However, participants were averse to arguments favouring disinfection based on cost savings.

“I would want to be 100% sure it was safe and not just a cost cutting means.”

Nurse, New Zealand European, female

Availability of clear scientific evidence and confidence in the process is essential. Acceptability of PPE disinfection for reuse was dependent on availability of scientific evidence that the disinfection process was effective, that PPE retains its material integrity in the disinfection process, and that it remains compliant with safety standards (albeit that current manufacturers' standards recommend single use of PPE).

“How often can PPE's (especially gowns) get disinfected? Would constant disinfection lead to the degradation of products? Will there be quality control for these products?”

Nurse, Asian, female

	Medical (n=269)	Nursing (n=468)	Dental (n=86)	Allied health (n=486)	Other health (n=102)	Total (n=1411)
Not comfortable reusing disinfected PPE under any circumstances (even if this would mean no PPE was available for use)	8 (3%)	77 (16%)	9 (10%)	94 (19%)	27 (26%)	215 (15%)
Would be comfortable under certain circumstances*	261 (97%)	391 (84%)	77 (90%)	392 (81%)	75 (74%)	1196 (85%)
Supply shortages	207 (77%)	293 (63%)	64 (74%)	285 (59%)	54 (53%)	903 (64%)
Pandemic situations	163 (61%)	193 (41%)	46 (53%)	176 (36%)	37 (37%)	615 (44%)
Non-pandemic situations	185 (69%)	216 (46%)	55 (64%)	274 (56%)	42 (41%)	772 (55%)
Types of PPE participants would reuse after disinfection*						
Filtering facepiece respirators	161/261 (62%)	114/391 (29%)	37/77 (48%)	136/392 (35%)	27/75 (36%)	475/1196 (40%)
Surgical masks	119/261 (46%)	77/391 (20%)	30/77 (39%)	126/392 (32%)	21/75 (28%)	373/1196 (31%)
Gowns	217/261 (83%)	220/391 (56%)	69/77 (90%)	252/392 (64%)	49/75 (65%)	807/1196 (67%)
Face shields	250/261 (96%)	358/391 (92%)	73/77 (95%)	354/392 (90%)	64/75 (85%)	1099/1196 (92%)
Eyewear	251/261 (96%)	369/391 (94%)	75/77 (97%)	357/392 (91%)	68/75 (91%)	1120/1196 (94%)

Data are n (%). PPE=personal protective equipment. *Multiple responses possible, so totals add up to more than 100%.

Table 3: Hypothetical acceptability of using PPE after disinfection, by profession

Panel 1: Themes identified from open-text comments**Personal protective equipment (PPE) reuse is already occurring**

- “I found the surgical masks can be washed with soapy water, although ideally a quick row of stitching up the sides to secure the pleats and elastic would be advisable.”—*Optometrist, New Zealand European, female*
- “Masks can be put in sunlight apparently which I did when there was no supplies and I heard bugs go away after 3 days so I also rotated gear.”—*Health-care assistant, New Zealand European, female*
- “I felt quite vulnerable when we didn’t have enough face masks (surgical) to wear and was told to hang them out on the clothesline to air and then reuse. With the 1st wave we were only given 3 masks at a time, this was to do anywhere up to 12 clients a day.”—*Health-care assistant, Māori, female*
- “At [hospital], we actually collected and reprocessed N95 masks (one manufacturer’s products only) due to shortages. None were released as they were for emergency issue only. We utilised a process already tested in the US and adopted quality control.”—*Infection control, New Zealand European, male*
- “I’d need to be very confident that it was safe to reuse—but I know we resterilise sterile supplies for use all over the hospital and operating theatres every day.”—*Nurse, New Zealand European, female*

Health-care workers recognise multiple benefits to reusing disinfected PPE

- “Show me the science that disinfection works and is safe and I see no reason we shouldn’t reuse and recycle to ensure supply remains available for our people. NZ is at the bottom of the world and last in line for supply chain delivery—we should be self-sufficient from locally sourced PPE, gowns, masks, eye wear and gloves.”—*Consultant doctor, New Zealand European, female*
- “I am all about reusing equipment where safe/possible to save the environment. So, granted it has been safely disinfected/sterilised, I would re-wear PPE.”—*Dental hygienist, Māori, female*
- “If we could disinfect our PPE it would be great because I’ve gone from filling 4 bags to nearly 20 bags of rubbish per week.”—*Dental hygienist, Niuean, female*
- “If there was access to sterilisation of PPE, I believe our practice would have jumped at the opportunity. We would have been more likely to be able to give definitive care to our patients rather than just writing prescriptions.”—*Dentist, New Zealand European, female*
- “I am totally all for a solution for the insane amount of medical waste our professions produce. Obviously, I understand that there are reasons for things to be single use, and of course it is of paramount importance to me to maintain high cross-infection standards, but if there is a way to maintain those standards and throw away less plastic, I couldn’t support it more. We definitely have to look for more

sustainable solutions. In my profession, the amount of plastic waste we throw out in one day is bordering on ridiculous. The environment matters, you’d be stupid not to realise that, if we don’t find solutions, we won’t have a world left to practice our professions in.”—*Dentist, Middle Eastern, female*

Availability of clear scientific evidence and confidence in the process is essential

- “I think disinfection of PPE is a great idea but would like to know how specifically it works and if the disinfection processes are adequate while still maintaining the integrity of the product.”—*Physiotherapist, New Zealand European, female*
- “Disinfection on a large scale would be difficult & require considerable logistical & organisational planning, which I doubt that [Local District Health Board] management team is capable nor highly motivated to accomplish.”—*Consultant doctor, New Zealand European, female*
- “If there were to be a possible shortage, I think disinfecting PPE gear a feasible solution. We have a duty of care in that we provide care safely while protecting ourselves from transference from us to community and community to us. Always at [the] back of mind is, “[is] this client before me Covid positive [...]. I have family, elderly parents. How do I keep myself protected to protect others and how do I protect those around me.” If it means using disinfected PPE gear and best scientific evidence supports this, then that is what we have to do I think.”—*Nurse, Māori*

Acceptability is negotiated based on perceived level of risk

- “I would only want to use this as a back-up if PPE supplies were getting low.”—*Nurse, New Zealand European, female*
- “I think most of my staff are happy with trying to reduce waste especially when no current cases of Covid in the South Island, and with some of the poorer quality products of PPE we have received I think they would be willing, so long as the process has been effectively and proven tested, would be happy to comply.”—*Dental hygienist, Māori, female*
- “I’m happy to reuse appropriately disinfected items such as visors/face shields and even gowns, but not so keen on reusing masks that have become moist with users’ breath (and patients’ coughs from the outside) and been rubbed against their skin—happy to have this view challenged though with sufficient evidence and education. And in the case of N95 style masks, happy to reuse these if my own one could be disinfected and returned to me.”—*Physiotherapist, New Zealand European, female*
- “I wouldn’t advocate reuse of masks despite cleaning and disinfection. Draws parallels with reusing condoms in my opinion.”—*Consultant doctor, New Zealand European, female*
- “Disinfection of PPE should be an absolute last-ditch effort for staff safety.”—*Anaesthetic technician, New Zealand European, male*

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Acceptability of PPE disinfection for reuse is contingent on trust

- “I think MOH [Ministry of Health] should be honest and make a clear open plan to safely clean, store and have the option to reuse...” — *Consultant doctor, New Zealand European, female*
- “I wouldn’t be happy about reusing PPE as I don’t trust management to not do it on the cheap. But if that was what was available, I would use them.” — *Nurse, New Zealand European, female*
- “While I feel that at times of true lack of PPE, reuse may be an acceptable option, I also feel that due to the current arrangements for the supply chain, this may be seen as the easier and cheaper option by the DHB [District Health Board] administration, for whom employees’ well-being and safety

has not been the highest priority.” — *Midwife, New Zealand European, female*

- “We put up with a lot of s**t as health workers. [...] and now y’all are going to try and tell us that our right to feeling safe at work isn’t important? This is where I draw the line. I’m willing to bet that disinfection isn’t going to be 100% either. The figureheads at the top will stand up in front of the public and tell them there’s plenty of PPE, that there isn’t a supply shortage, simply to cover their a*** that they didn’t plan for a pandemic. If it gets to the point of recycling/using disinfected PPE, I am quitting the profession.” — *Nurse, Asian, female*

Quotes not to be taken as evidence-based practice recommendations.

Participants also expressed concern about how the disinfection process would work and identified numerous logistical issues:

“Does the evidence show it’s okay to reuse—including data for the specific kit we have? Are our local services able to replicate the disinfection conditions that are outlined in the evidence base? Can our local services be up-scaled to efficiently take on the work required to process all of the PPE that needs to be disinfected?”

Pharmacist, New Zealand European, female

The “look and feel” of the final product was considered important as a proxy indicator of confidence in the disinfection process. One participant, believing that PPE would not retain its appearance after disinfection, commented:

“Personally, I would not wear a recycled mask for aesthetic reasons.”

Consultant doctor, Other ethnicity, male

For those reporting being uncomfortable with PPE disinfection for reuse (about 15%), key concerns were lack of evidence for safe disinfection, concerns that PPE quality would deteriorate post disinfection, the lack of sterility, non-compliance with current PPE standards, and concerns about negative health impacts from disinfection methods.

“I am not aware of current effective processes for disinfection of each item of PPE and would need to see substantiated research of the protocol for disinfection and its efficacy before considering this as an option. Currently PPE is recommended by manufacturers for single use only. I am also currently bound by legislated registration authority practice guidelines.”

Dentist, New Zealand European, female

Acceptability is negotiated on the basis of perceived risk level. More nuanced factors affecting overall level of acceptability of disinfected PPE considered by participants included perceived risk level of particular

situations. These negotiated factors included pandemic status, current PPE supply levels, whether participants would receive their own PPE back, if PPE were used for droplet precautions or aerosol-generating procedures such as tracheal intubation, nature of materials, patient level of risk, and extent of patient contact.

“Initially it was the shortage of basic surgical masks and gowns and not knowing if we would be able to get more that made us reuse gowns and the same mask for the day or part of a day. We weren’t seeing ‘viral’ patients or taking swabs at that stage but doing lots of flu vax [vaccinations] so had patient contact but were probably at a reasonably low risk.”

Nurse, New Zealand European, female

For some participants, only PPE constructed from “hard materials” or PPE that had no patient contact were perceived to be more acceptable for disinfection.

“Would not reuse gloves but masks do not [make] contact [with] my next patient...neither would a face shield.”

Dentist, New Zealand European, male

The relative importance of chain of identity was also not universally agreed upon. Some participants felt that chain of identity would be important to mitigate their initial opposition to mask disinfection.

“I would be OK with reusing all PPE after disinfection except masks. Even if it was backed with very rigorous science, there is still a gross factor to it. The way that could be minimised would be my own masks returning to me.”

Nurse, New Zealand European, female

However, other participants viewed receiving their own PPE back as a preferential but not a necessary element of the PPE disinfection and reuse process:

“Reassurance of the cleaning process, especially for masks that you breathe in, feels most important for me if reuse is to happen. Ideally this would also mean return of my own PPE, but I recognise the additional logistical challenges in this, and the main thing is to prevent

Panel 2: Recommendations from end users for the disinfection of PPE for potential reuse

- Scientific evidence of the efficacy of any proposed personal protective equipment (PPE) disinfection method and that material integrity is maintained post disinfection provided to the end user
- Clearly communicated rationale and process for PPE disinfection and potential reuse provided
- Logistical issues of PPE disinfection, including how PPE will be collected, transported, and delivered post disinfection mapped out and well communicated
- Chain of identity of PPE considered, and clear communication as to why this is or is not utilised in any PPE disinfection solution provided
- Final disinfected PPE product must be tidy and presentable, to alleviate any aesthetic concerns about wearing a single-use medical product more than once
- Involvement of health professionals in the PPE disinfection process logistics (and communication of any solution) to enhance a sense of solutions that are by, with, and for health professionals

COVID spread, so if it came down to it, I'd wear anyone's previous PPE provided it had been disinfected."

Consultant doctor, New Zealand European, female.

For some participants there was an idea that PPE is single-use only "for a reason" and a repulsion towards the idea of disinfecting any type of mask. The perceived physical closeness of PPE meant that it could not be treated in the same way as other medical equipment that might be sterilised between uses.

"reusing facemasks used by someone else would be icky".

Nurse, New Zealand European, female

However, participant accounts suggested that these factors could be negotiated if required, depending on the circumstances. Some participants who initially were reluctant to reuse PPE appeared to have a threshold where supply circumstances might become intolerable beyond which PPE reuse would then be acceptable.

"I strongly dislike the idea of reusing any PPE, but in the event that supply was genuinely low, I'd rather use disinfected PPE than no PPE. I would consider refusing to work if there was insufficient PPE."

Nurse, Māori, female

Acceptability of PPE disinfection for reuse is contingent on trust in the organisation. Distinct from confidence in the disinfection process, acceptability was contingent on participants trusting the organisation and workplace implementing a disinfection and reuse policy, with a culture of clear communication, transparency, and respect. Although seldom reported, participants' positive recollections of reuse suggested this was more acceptable when health-care workers were engaged in transparent decision-making processes: "

We reused N95 masks, after extensive discussion on how to do this safely, in which all members of the team who were involved in wearing PPE were included and

had no issues with it. However, as more information was obtained, we would always look to change/improve on our practice in the future."

General practitioner, New Zealand European, male

Similarly, those opposed to PPE disinfection alluded to low-trust work environments where they felt undervalued.

"Management didn't trust staff to use PPE wisely. Emails were sent (from them in the safety of their offices) berating staff for being careless, wasteful, stealing... whilst of course expecting us to be real heroes and take it for the team. If the decision to disinfect and reuse PPE comes from the DHB [District Health Board] then I have no faith. If it comes from a sector that has scientific evidence that proves that the process is 100% effective and safe, then yes, definitely worthy of consideration."

Nurse, New Zealand European, female

Multiple participants recalled PPE being reused in their organisations, and management recommending this strategy, highlighting that PPE reuse occurred in multiple centres in New Zealand during the first wave, often without clear communication or scientific rationale.

Discussion

Our findings indicate acceptance with caveats of PPE disinfection for reuse among health-care workers in New Zealand, with 85% indicating comfort with reuse after disinfection. Variability existed regarding when PPE reuse was acceptable, with lower acceptability for surgical masks and FFRs. Most respondents favoured reuse when there were supply shortages. Thematic analysis indicated that PPE reuse was already occurring, corroborating the quantitative data, and reflecting what has occurred globally.¹⁰ Health-care workers recognised multiple benefits of reusing disinfected PPE, including reduced medical wastage. Acceptance of disinfection and reuse is contingent on availability of scientific evidence supporting the efficacy of PPE disinfection and confidence in the process, the perceived level of risk, and trust in the organisation and workplace implementing PPE reuse. There were reported examples in the survey responses in which PPE disinfection or reuse had been undertaken without causing concerns among staff. Health-care worker involvement in logistics and process communication was crucial, with a clear rationale and need having been identified by health-care workers themselves.

Importantly, there was recognition of the importance of medical wastage reduction, with 34% of participants agreeing it was "somewhat important" and 42% of participants agreeing it was "very important". Qualitative comments reflected this as a key benefit, with a strong sense that disinfection and reuse could help mitigate some of the environmental impacts of the pandemic. Collapse of waste management chains has been an area of concern since early in the pandemic.^{5,25} For example, in southeast Asia, there have been substantial increases in medical

wastage because of COVID-19.²⁶ Reuse after disinfection would help address these environmental concerns. However, safety of health-care workers and other front-line workers is crucial in any PPE disinfection solution.

There are few data describing factors affecting acceptability of PPE disinfection for reuse practices among health-care workers. A study of strategies for extended use, reuse, or preservation of PPE suggested that so-called “chain of custody” can make disinfection more acceptable among health-care workers,²⁷ with clear markings to signify both the number of reuse cycles and evidence that the PPE has been disinfected,²⁸ although there was less agreement on the importance of chain of custody in our study. Our data suggest a complex process of risk assessment undertaken by participants, including consideration of PPE supply (whereby reusing disinfected PPE was perceived to be better than the alternative of no PPE) and rates of transmission. More participants seemed comfortable with PPE reuse under non-pandemic conditions, perhaps due to perceived risk of transmission or the level of pressure on the health system.

Past research demonstrates the central role of trust in both the disinfection process¹⁶ and the organisation.²⁹ In our study, both younger age and ethnicity (New Zealand European) were associated with greater acceptance of PPE disinfection. These results might reflect age and ethnic group differences in levels of trust in health-care organisations or central government and their ability to protect health-care workers. Racial discrimination with regard to PPE access and usage has been reported among Black, Asian, and ethnic minority doctors in the UK.³⁰ Organisations seeking to implement disinfection practices must ensure they create a culture of trust, open communication, transparency, and cultural safety within their organisations to facilitate confidence among all health-care workers.²⁹

There were no discernible differences in the perspectives of the various health-care professions in either analysis. However, whether the views reported here by health-care workers in New Zealand would be directly applicable to other countries remains uncertain. The proportion of participants reporting PPE reuse during the first wave (45%) was lower than the 80% reported in a previous international survey of health-care workers, conducted during the early stages of the pandemic.³¹ Nevertheless, our findings highlight pertinent factors that might feasibly influence the acceptability of PPE reuse in countries with a higher prevalence of COVID-19 cases. A previous WHO review of health worker preferences regarding PPE use in the context of Ebola and other infectious diseases showed that perception of risk and the safety climate were key factors influencing use and acceptability of PPE.³² Future research could repeat this survey in other jurisdictions and at other timepoints in New Zealand.

Before any potential adoption of PPE disinfection for reuse, there are environmental, logistical, and economic

considerations worthy of future research. The materials used in PPE are comprised mainly of plastics and predominantly discarded in landfills; given the marked increase in PPE waste during the COVID-19 pandemic, there is an urgent need to address the finite waste stream of landfills, and reduce the volume of single-use PPE being utilised globally.³³ Costing exercises for particular disinfection units, including transport, emissions associated with disinfection, and number of disinfection cycles possible are all important areas of future research, should PPE disinfection for potential reuse be pursued.

The strengths of this study include the large number of participants from across New Zealand and the collection of qualitative responses that provide explanation and nuance to the quantitative data. Limitations include the unknown transferability of the findings to other national contexts, the inability to calculate response rate to the survey and thus characterise non-response bias due to the wide recruitment strategy and self-selection of participants, and the lack of available comparable demographic health workforce data. Conducting the study solely online without a postal or telephone option might have limited participation from some potential respondents. Although this study was also designed to include other front-line workers, such as police, fire service, and border workers, the low number of responses meant meaningful analyses of these data were not possible, so they were not included in this study. We acknowledge the importance of including these groups in further research. Furthermore, the survey was undertaken in the early stages of the pandemic, during which PPE supply was a strong concern. The attitudes recorded in our survey might therefore have been influenced by the acute crises of PPE shortages and the large increase in medical wastage during the global pandemic.

We acknowledge that front line terminology might not be the preference of many health-care workers, but is used to communicate the language being used in the media at the time. Quotes regarding PPE disinfection found in this study must not be taken as representative of safe practice, and represent the voice of individual health-care workers rather than scientific evidence.

While recognising several key caveats and the need for further studies on environmental aspects, cost, and number of disinfection cycles possible, PPE disinfection for reuse as a more sustainable health practice may be acceptable to health-care workers. Reuse was already prevalent during the first wave of COVID-19 in New Zealand, often taking place without standardised procedures. Front-line worker and patient safety should be the key consideration in any PPE disinfection solution moving forward; however, environmental considerations relating to medical waste are crucial given the increasing pressures on planetary health. Clear communication and transparency of process for any future PPE disinfection solution will be crucial to end-user acceptance of any potential solutions.

Contributors

CEKW was involved in study design, data collection, analyses, interpretation, and writing of the manuscript. HW contributed to study design and critical appraisal of the manuscript. NC contributed to data analysis and critical appraisal of the manuscript. JGBD contributed to study design, analyses, interpretation, and critical appraisal of the manuscript. CCG contributed to study design and critical appraisal of the manuscript. TAS contributed to study design, interpretation, and critical appraisal of the manuscript. YCA oversaw the study and contributed to study design, analyses, interpretation, and critical appraisal of the manuscript. CEKW and JGBD accessed and verified the quantitative data and CEKW, NC, and YCA accessed and verified the qualitative data used in the study. All authors had full access to all the data used in the study and accept responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The anonymised data on which this manuscript were based could be made available to other investigators upon bona fide request and following all the necessary approvals (including ethics approval) of the detailed study proposal and statistical analyses plan. Any queries should be directed to Yvonne Anderson (yvonne.anderson@curtin.edu.au).

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