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State of the Science Review

## Impact of personal protective equipment use on health care workers' physical health during the COVID-19 pandemic: A systematic review and meta-analysis

Petros Galanis PhD<sup>a,\*</sup>, Irene Vraka MD, PhD<sup>b</sup>, Despoina Fragkou MSc<sup>a</sup>, Angeliki Bilali PhD<sup>c</sup>, Daphne Kaitelidou PhD<sup>a</sup><sup>a</sup> Faculty of Nursing, Center for Health Services Management and Evaluation, National and Kapodistrian University of Athens, Athens, Greece<sup>b</sup> Department of Radiology, P & A Kyriakou Children's Hospital, Athens, Greece<sup>c</sup> Hospital Waste Management Unit, P & A Kyriakou Children's Hospital, Athens, Greece

## Key Words:

Adverse events  
SARS-CoV-2  
Risk factors  
Health care staff  
Headaches  
PPE

## A B S T R A C T

**Background:** During the coronavirus disease 2019 (COVID-19) pandemic, health care workers (HCWs) have been obliged to wear personal protective equipment (PPE). We assessed the impact of PPE use on HCWs' physical health and we examined factors related to a greater risk of adverse events due to PPE use.**Methods:** We applied the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines and the Cochrane criteria. We searched PubMed, Medline, Scopus, ProQuest, CINAHL, and medRxiv from January 1, 2020 to December 27, 2020.**Results:** Our review included 14 studies with 11,746 HCWs. The estimated overall prevalence of adverse events among HCWs was 78% with a range from 42.8% to 95.1% among studies. Among others, the following factors were related to the risk of adverse events among HCWs due to PPE use: obesity, diabetes mellitus, smoking, pre-existing headache, longer duration of shifts wearing PPE, increased consecutive days with PPE, and increased exposure to confirmed or suspected COVID-19 patients.**Conclusions:** The frequency of adverse events among HCWs due to PPE use is very high. Healthcare facilities should take the necessary precautions and change the working conditions during the COVID-19 pandemic to prevent adverse events associated with PPE use and minimize harm to HCWs.

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## BACKGROUND

Health care workers (HCWs) can be exposed to the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) through clinical settings or community transmission and are essential workers at risk for coronavirus disease 2019 (COVID-19). According to the Centers

for Disease Control and Prevention (CDC) during February 12–July 16, 2020, in the USA, 11% of patients had been identified as HCWs,<sup>1</sup> while during March 1–May 31, 2020, among hospitalized adults, 5.9% were HCWs.<sup>2</sup> A meta-analysis<sup>3</sup> found that the prevalence of hospitalization among HCWs infected with COVID-19 is 15.1% and the mortality is 1.5%, while another meta-analysis<sup>4</sup> found that the proportion of SARS-CoV-2 positive HCWs among all COVID-19 patients is 10.1% and the mortality is significantly lower in HCWs as compared to that of all patients (0.3% vs 2.3%). According to an analysis that included studies only in Australia between January 25th and July 8th, HCWs were 2.69 times more likely to contract COVID-19 than the general population.<sup>5</sup> Also, the seroprevalence of SARS-CoV-2 antibodies among HCWs is high (8.7%) especially in North America (12.7%) compared to Europe (8.5%), Africa (8.2%), and Asia (4%).<sup>6</sup>

During the COVID-19 pandemic, HCWs caring for patients with COVID-19 in high-risk clinical settings such as isolation wards,

\* Address correspondence to: Petros Galanis, PhD, Faculty of Nursing, Center for Health Services Management and Evaluation, National and Kapodistrian University of Athens, 123 Papadiamantopoulou street, GR-11527, Athens, Greece.

E-mail address: [pegalan@nurs.uoa.gr](mailto:pegalan@nurs.uoa.gr) (P. Galanis).

Author contributions: P.G., I.V. and D.K. were responsible for the conception and design of the study. P.G., I.V., D.F., A.B. were responsible for the acquisition, analysis and interpretation of data. All the authors drafted the article or revised it critically for important intellectual content, and provided final approval of the version to be submitted.

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intensive care units, emergency rooms, and general medical wards have been obliged to wear personal protective equipment (PPE). PPE includes equipment or specific clothing (eg, respiratory and eye protection, gown and gloves) that protects HCWs against infectious materials.<sup>7</sup> The necessity of PPE to prevent transmission of viruses to HCWs has already proven during the severe acute respiratory distress syndrome (SARS)<sup>8</sup> and the Ebola epidemic.<sup>9</sup> During the COVID-19 pandemic, HCWs have to wear PPE unceasingly for more than 6–8 hours in a shift. Moreover, inappropriate PPE reuse (eg, donning of a used PPE item without contamination) due to global PPE shortages remains affecting HCWs and patients' safety and the sustainability of health care systems.<sup>10–13</sup> Under these circumstances, World Health Organization diffuses recommendations for optimizing PPE use by HCWs caring for suspected or confirmed COVID-19 patients especially in countries with severe PPE shortages.<sup>7</sup>

Several studies have already shown that adverse reactions from PPE use among HCWs are common including dermatitis, allergy, atopy, facial itch, acne, rash, etc.<sup>14–18</sup> Considering the long-time wearing of PPE among HCWs and PPE shortages during the COVID-19 pandemic, we anticipated a high incidence of physical health problems due to PPE use among HCWs. To our knowledge, the overall impact of PPE use on HCWs' physical health during the COVID-19 pandemic is unknown. Thus, the primary aim of this systematic review and meta-analysis was to assess the impact of PPE use on HCWs' physical health during the COVID-19 pandemic. The secondary objective was to examine factors related to a greater risk of adverse events among HCWs due to PPE use.

## METHODS

### Data sources and strategy

We applied the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines<sup>19</sup> and the Cochrane criteria<sup>20</sup> for this systematic review and meta-analysis. We searched PubMed, Medline, Scopus, ProQuest, CINAHL, and preprint services (medRxiv) from January 1, 2020 to December 27, 2020. Also, we examined reference lists of all relevant articles and we removed duplicates. We applied the following filters during the search in the databases: humans, English language, and journal article. We used the following strategy searching in title/abstract query: (("health care worker\*" OR "healthcare worker\*" OR "healthcare personnel" OR "health care personnel" OR "health personnel" OR "health care professional\*" OR "healthcare professional\*" OR staff OR "nursing staff" OR professional\* OR worker\* OR doctor\* OR physician\* OR clinician\* OR nurs\* OR midwives OR midwife\* OR paramedic\* OR practitioner\*) AND ("personal protective equipment")) AND (COVID-19 OR COVID19 OR COVID OR SARS-CoV\* OR "Severe Acute Respiratory Syndrome Coronavirus\*" OR coronavirus\*). The study protocol was registered with PROSPERO (CRD42021228221).

### Selection and eligibility criteria

Two independent reviewers performed study selection and discrepancies were resolved by a third, senior reviewer. We initially screened title and abstract of the records and then full-text. We included studies that examine the impact of PPE use on HCWs' physical health during the COVID-19 pandemic. Also, we included studies examining factors related to a greater risk of adverse events among HCWs due to PPE use. We examined articles that were published in English, except reviews, qualitative studies, protocols, case reports, editorials, and letters to the Editor. All types of HCWs directly involving in the management of COVID-19 patients were accepted for inclusion, while we excluded studies with health care students and the

general population. Also, we excluded studies that examined the effects of PPE use on the psychological or mental health of HCWs.

### Data extraction and quality assessment

We extracted the following data from each study: authors, location, sample size, age, gender, study design, sampling method, assessment of the adverse events, response rate, data collection time, type of publication (journal or preprint service), number and type of adverse events among HCWs, factors related to a greater risk of adverse events, and the level of analysis (univariate or multivariable).

Two reviewers used the Joanna Briggs Institute critical appraisal tools to assess the quality of studies as poor, moderate, or good.<sup>21</sup> Regarding cross-sectional studies, an 8-point scale is used with a score of  $\leq 3$  refers to poor quality, a score of 4–6 points refers to moderate quality, and a score of 7–8 points refers to good quality.

### Statistical analysis

For each study, we extracted the sample size and adverse events that occurred among HCWs due to PPE use. We initially calculated the prevalence of any adverse event and the 95% confidence interval (CI) for each included study. Then, we transformed these prevalences with the Freeman-Tukey Double Arcsine method before pooling.<sup>22</sup> Moreover, we pooled the results for adverse events that occurred among HCWs at least in three studies. We assessed between-studies heterogeneity with the Hedges Q statistic and  $I^2$  statistics.  $I^2$  values higher than 75% indicate high heterogeneity, while a  $P$ -value  $< .1$  for the Hedges Q statistic indicates statistically significant heterogeneity.<sup>23</sup> A random effect model was applied to estimate pooled effects since the heterogeneity between results was very high.<sup>23</sup> A leave-one-out sensitivity analysis was performed to determine the influence of each study on the overall effect. We used a funnel plot and the Egger's test to assess the publication bias with a  $P$  value  $< .05$  indicating publication bias.<sup>24</sup> A priori, we considered gender, age, sample size, the continent that studies were conducted, studies quality, study design, assessment of the outcome, data collection time, and publication type (journal or preprint service) as sources of heterogeneity. Due to the limited data and limited variability of some of these variables, we decided to perform meta-regression analysis and subgroup analysis considering gender, sample size, studies quality, and data collection time as sources of heterogeneity. We did not perform a meta-analysis for the factors related to the occurrence of adverse events among HCWs since the data were very limited and highly heterogeneous. We used the OpenMeta[Analyst] to perform meta-analysis.<sup>25</sup>

## RESULTS

### Identification and selection of studies

Flowchart of the literature search is summarized in PRISMA format and it is shown in Figure 1. We initially identified 2,699 potential records through PubMed, Medline, Scopus, ProQuest, CINAHL, and medRxiv removing duplicates. After the screening of the titles and abstracts, we removed 2,671 records and we added 4 more records found by the reference lists scanning. Finally, we included 14 studies<sup>26–39</sup> in this meta-analysis that met our inclusion criteria.

### Characteristics of the studies

Main characteristics of the studies included in our systematic review and meta-analysis are shown in Table 1. A total of 11,746 HCWs from 16 countries were included in this review. Number of HCWs in studies ranged from 40 to 4,306, while females' percentage

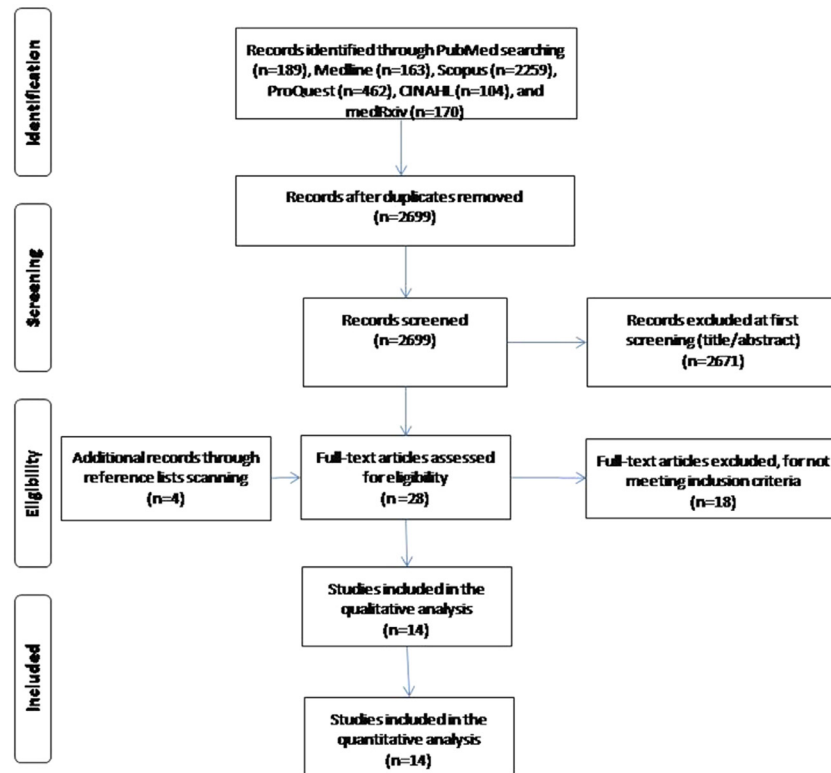


Fig 1. Flowchart of the literature search according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

ranged from 46.0% to 91.8%. The majority of studies were conducted in Asia ( $n = 10$ ),<sup>26,28,30-33,35,36,38,39</sup> 2 studies were conducted in Europe,<sup>34,37</sup> one study was conducted in South America,<sup>27</sup> and one study included HCWs from 10 countries.<sup>29</sup> All studies were cross-sectional, while 13 studies<sup>26-30,32-39</sup> used a convenience sample method and one study<sup>31</sup> used a purposeful sampling method. Assessment of adverse events was self-reported through questionnaires in 13 studies,<sup>26-35,37-39</sup> while in one study<sup>36</sup> a clinical diagnosis was performed. All studies were published in journals and seven studies<sup>26,28,29,31,32,38,39</sup> reported response rate.

#### Quality assessment

Quality assessment of cross-sectional studies included in this systematic review is shown in Table 2. Quality was poor in 9 studies<sup>26,29,31,33-37,39</sup> and moderate in 5 studies.<sup>27,28,30,32,38</sup>

#### Meta-analysis

A random effect model was applied to estimate the pooled prevalence of adverse events since the heterogeneity between results was very high ( $I^2 = 99.39$ ,  $P$  value for the Hedges  $Q$  statistic  $<0.001$ ). The estimated overall prevalence of adverse events among HCWs was 78% (95% CI: 66.7%-87.5%; Fig 2). Prevalence among studies ranged from 42.8%<sup>30</sup> to 95.1%.<sup>31</sup> A leave-one-out sensitivity analysis showed that no single study had a disproportional effect on the pooled prevalence, which varied between 76.4% (95% CI: 64.5%-86.4%), with Hu et al.<sup>31</sup> excluded, and 80.3% (95% CI: 73.8%-86.1%) with Jiang et al.<sup>30</sup> excluded (Web Fig 1). A publication bias was potential since  $P$  value for Egger's test was  $<0.05$  and the shape of the funnel plot was asymmetrical (Web Fig 2).

According to subgroup analysis, the prevalence of adverse events was higher for the studies with poor quality (83.5% [95% CI: 75.4%-90.2%],  $I^2 = 97.64$ ) compared to those with moderate quality (67.1%

[95% CI: 50.4%-81.8%],  $I^2 = 99.13$ ). Meta-regression analysis identified that increased sample size was related to decreased prevalence of adverse events among HCWs ( $P < .001$ ; Web Fig 3). Also, the prevalence of adverse events was independent of the gender distribution ( $P = .32$ ), and data collection time ( $P = .63$ ).

Adverse events among HCWs due to personal protective equipment use during COVID-19 pandemic are listed in Table 3. We pooled the results for adverse events that occurred among HCWs at least in three studies and the results are presented in Table 4. According to the pooled results, the adverse events that occurred more often were headache (55.9% [95% CI: 35.8%-75.0%]), dry skin (54.4% [95% CI: 25.4%-81.8%]), dyspnoea (53.4% [95% CI: 27.2%-78.6%]), pressure injuries (40.4% [95% CI: 27.7%-53.8%]), itching (39.8% [95% CI: 16.2%-66.3%]), hyperhidrosis (38.5% [95% CI: 15.3%-64.9%]), and dermatitis (31.0% [95% CI: 11.1%-55.5%]).

#### Risk factors for adverse events

Eleven studies<sup>26-33,35,38,39</sup> investigated risk factors for adverse events among HCWs due to personal protective equipment use during the COVID-19 pandemic (Table 5). Six studies<sup>21,27,28,32,38,39</sup> used multivariable models to eliminate confounding factors, while all studies except one<sup>33</sup> measured the occurrence of any adverse event as the dependent variable.

We found that demographic, clinical, and job characteristics were related to the risk of adverse events among HCWs due to PPE use.

Regarding gender, four studies<sup>31,33,35,38</sup> found that females had a higher risk of adverse events with ORs ranging from 1.87 to 3.20, while one study<sup>30</sup> found the opposite (OR:1.54 for males). A higher proportion of nurses were typically females and this possible confounder could be a reason that females found at higher risk of adverse events. Moreover, four studies<sup>27,31,33,35</sup> showed that younger age was associated with increased risk of adverse events, while one study<sup>26</sup>

**Table 1**  
Main characteristics of the studies included in this systematic review

Reference	Location	Sample size (n)	Age, mean (SD)	Females (%)	Study design	Sampling method	Assessment of the adverse events	Response rate (%)	Data collection time	Publication in
Zhao et al. 2020 <sup>26</sup>	China	960	33 (23-43) <sup>a</sup>	64.3	Cross-sectional	Convenience sampling	Self-reported	27.6	April 21 to May 15	Journal
Coelho et al. 2020 <sup>27</sup>	Brazil	1106	34.1 (8.9)	83.6	Cross-sectional	Convenience sampling	Self-reported	NR	May 15-20	Journal
Çağlar et al. 2020 <sup>28</sup>	Turkey	315	31.6 (4.6)	50.5	Cross-sectional	Convenience sampling	Self-reported	43.4	August 01 to September 01	Journal
Tabah et al. 2020 <sup>29</sup>	Australia, Italy, United Kingdom, France, Libya, Portugal, Austria, Argentina, Netherlands, Belgium	2711	41 (34-49) <sup>a</sup>	46.0	Cross-sectional	Convenience sampling	Self-reported	56.0	March 30 to April 20	Journal
Jiang et al. 2020 <sup>30</sup>	China	4306	32.5 (7.1)	88.0	Cross-sectional	Convenience sampling	Self-reported	NR	February 8-22	Journal
Hu et al. 2020 <sup>31</sup>	China	61	20-29 years: 26.3%; 30-39 years:67.2%; 40-49 years:4.9%; 50-59:1.6%	91.8	Cross-sectional	Purposeful sampling	Self-reported	93.8	February	Journal
Ong et al. 2020 <sup>32</sup>	Singapore	158	21-40 years: 87.3%; >40:12.7%	70.3	Cross-sectional	Convenience sampling	Self-reported	98.7	February 26 to March 8	Journal
Metin et al. 2020 <sup>33</sup>	Turkey	526	34 (7)	69.2	Cross-sectional	Convenience sampling	Self-reported	NR	April 05-12	Journal
Guertler et al. 2020 <sup>34</sup>	Germany	40	32 (6.9)	52.5	Cross-sectional	Convenience sampling	Self-reported	NR	April 01-14	Journal
Yildiz et al. 2020 <sup>35</sup>	Turkey	553	20-30 years: 62.4%; 31-40 years:23.5%; 41-50 years:12.7%; >50:1.4%	70.0	Cross-sectional	Convenience sampling	Self-reported	NR	April 15 to May 15	Journal
Singh et al. 2020 <sup>36</sup>	India	43	32.8 (14.5)	90.7	Cross-sectional	Convenience sampling	Clinical diagnosis	NR	March 24 to April 16	Journal
Battista et al. 2020 <sup>37</sup>	Italy	185	32.6 (8.3)	68.6	Cross-sectional	Convenience sampling	Self-reported	NR	April 20 to May 04	Journal
Lin et al. 2020 <sup>38</sup>	China	376	32.2 (6.5)	77.7	Cross-sectional	Convenience sampling	Self-reported	37.6	February 6-11	Journal
Zuo et al. 2020 <sup>39</sup>	China	404	NR	75.2	Cross-sectional	Convenience sampling	Self-reported	69.8	February 01-28	Journal

<sup>a</sup>Median (interquartile range),NR = not reported.

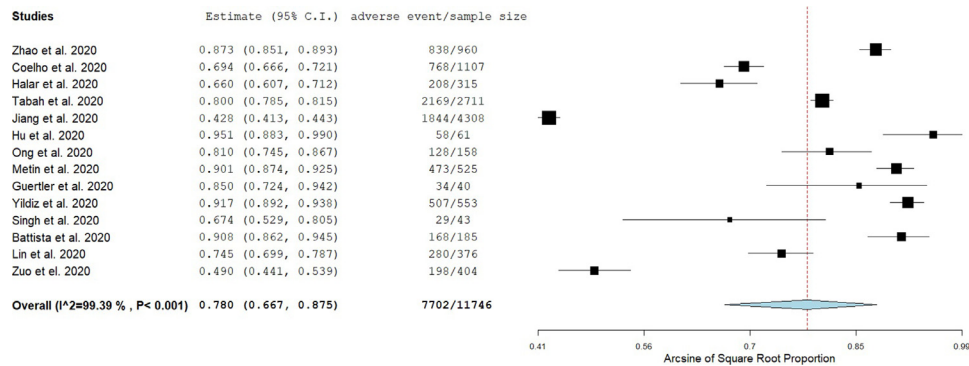


Fig 2. Forest plot of the prevalence of adverse events among health care workers.

showed the opposite. Among HCWs, nurses and physicians were at a greater risk of developing adverse events.<sup>26</sup>

Several clinical characteristics of the HCWs affected the occurrence of adverse events. In particular, comorbidity such as diabetes mellitus, obesity, pre-existing headache, and smoking significantly increased the risk of adverse events.<sup>28,32,33</sup> Similar, heavy sweating was a risk factor for adverse events.<sup>30</sup>

We found that job characteristics affected adverse events in a significant way. The longer duration of shifts wearing PPE, the greater the risk of adverse events with ORs ranging from 1.24 to 4.26.<sup>27-30,32,38</sup> Two studies<sup>27,38</sup> found that shifts >6 hours was a risk factor, while 2 studies<sup>32,39</sup> found a different cut-off point of 4 hours. Moreover, increased consecutive days with PPE<sup>26,28</sup> and higher grade of PPE<sup>30,39</sup> significantly increased risk of adverse events among HCWs. Our review showed that increased exposure to confirmed or suspected COVID-19 patients,<sup>26,33,38</sup> working in hospitals with a more severe epidemic,<sup>38</sup> and no use of prevention inputs<sup>27</sup> increased the probability of adverse events.

## DISCUSSION

To our knowledge, this is the first systematic review and meta-analysis that investigates the impact of PPE use on HCWs' physical health during the COVID-19 pandemic. Also, we searched for risk factors related to adverse events among HCWs.

We found that the overall prevalence of adverse events among HCWs was very high (78%) with a wide range from 42.8% to 95.1% among studies. PPE use among HCWs is related to skin reactions such as dermatitis, allergy, atopy, facial itch, acne, rash.<sup>14-18</sup> HCWs wear PPE items for long periods of time due to the shortage of PPE especially at the beginning of the COVID-19 pandemic and the increased workload in healthcare facilities.<sup>40,41</sup> This scenario increases considerably the risk of adverse events such as skin reactions. The problem is further complicated by the lack of training and awareness among HCWs about the use of PPE.<sup>42,43</sup> During the COVID-19 pandemic, HCWs have to encounter several challenges regarding PPE such as donning (putting on) and doffing (taking off) equipment in the appropriate way, wearing PPE items for long periods of time, difficulties in communication with patients and colleagues etc.<sup>44,45</sup> HCWs should undergo compulsory training on the correct use of PPE using video training and simulations than traditional methods of teaching.<sup>7,45</sup>

According to our results, the most prevalent physical complaint from the use of PPE was headaches. Previous studies confirm that headaches are common among HCWs when the filtering facepiece respirator is used especially for a prolonged period.<sup>46-48</sup> It is well known that headaches could arise from the continuous pressure of pericranial soft tissues by putting on objects with tight straps around

the head, for example, helmets, hats, goggles.<sup>49-51</sup> Also, breathing discomfort due to filtering facepiece respirator has also been reported in the literature confirming our finding that dyspnoea is a common adverse event among HCWs due to PPE use.<sup>52-54</sup> A survey among dental professionals during the COVID-19 pandemic found that the prolonged use of filtering facepiece 2 (FFP2) respirators was related to moderate breathing difficulties.<sup>55</sup> Moreover, increased levels of anxiety and stress among HCWs during the pandemic<sup>56,57</sup> may contribute to breathing difficulties.

We found that skin reactions (eg, dry skin, itching, dermatitis, and rash) were the most frequent adverse events that HCWs encountered. While increased use of gloves and filtering facepiece respirators and excessive sanitizing of hands among HCWs are indispensable to prevent transmission of SARS-CoV-2, they also have negative implications leading to a removal of normal bacterial flora and a disruption of the natural protective skin barrier.<sup>58-60</sup> In that case, the frequency and the severity of occupational skin diseases increase.<sup>61-63</sup>

Adverse events caused by PPE use are a comprehensive effect with sociodemographic, clinical, and job characteristics as the contributing factors. Regarding the sociodemographic factors, we found that gender, age, and type of occupation affect the impact of PPE use on HCWs' physical health. The effect of gender and age is controversial. In particular, 4 studies<sup>31,33,35,38</sup> found that adverse events are more common among females and one study<sup>30</sup> found the opposite. A multicenter survey in China<sup>64</sup> found a higher prevalence of pressure injuries in male hospitalized patients while another study with outpatients in Turkey<sup>65</sup> found that acne, hand eczema, and urticaria are more common in females and seborrheic dermatitis is more common in males. Differences in hormones, genetic factors, activity levels, hygiene behavior and use of skin care products could explain differences in skin reactions among males and females HCWs. Regarding age, four studies<sup>27,31,33,35</sup> found that younger age is related to a greater risk of skin reactions, while one study<sup>26</sup> found the opposite. Several studies found that skin reactions are more frequent in young adults.<sup>65-67</sup>

According to our review, comorbidity is a risk factor for new-onset symptoms from the PPE use. In particular, obesity, smoking, diabetes mellitus, and pre-existing headache were related to increased odds of adverse events. Obesity and smoking decrease cardiopulmonary capacity causing dyspnea.<sup>68,69</sup> Obese individuals and smokers could face more symptoms because of the use of filtering facepiece respirators without valve that brings difficulties in breathing. Laferty and McKay<sup>70</sup> found that filtering facepiece respirators cause breathing resistance resulting on a decrease in SpO<sub>2</sub> and an increase in CO<sub>2</sub> levels. Moreover, isolation gowns cover the entire body causing heavy sweating and continuous dehydration especially among smokers and obese individuals. A scoping review<sup>55</sup> among

**Table 2**  
Quality of cross-sectional studies included in this systematic review

	Zhao et al. 2020 <sup>26</sup>	Coelho et al. 2020 <sup>27</sup>	Çağlar et al. 2020 <sup>28</sup>	Tabah et al. 2020 <sup>29</sup>	Jiang et al. 2020 <sup>30</sup>	Hu et al. 2020 <sup>31</sup>	Ong et al. 2020 <sup>32</sup>	Metin et al. 2020 <sup>33</sup>	Guertler et al. 2020 <sup>34</sup>	Yildiz et al. 2020 <sup>35</sup>
1. Were the criteria for inclusion in the sample clearly defined?	X	X	X		X		X			
2. Were the study subjects and the setting described in detail?	X	X	X	X	X		X	X	X	X
3. Was the exposure measured in a valid and reliable way?										
4. Were objective, standard criteria used for measurement of the condition?										
5. Were confounding factors identified?		X	X		X		X			
6. Were strategies to deal with confounding factors stated?		X	X		X		X			
7. Were the outcomes measured in a valid and reliable way?										
8. Was appropriate statistical analysis used?	X	X	X	X	X	X	X	X	X	X
<b>Total quality</b>	Poor	Moderate	Moderate	Poor	Moderate	Poor	Moderate	Poor	Poor	Poor
	Singh et al. 2020 <sup>36</sup>	Battista et al. 2020 <sup>37</sup>	Lin et al. 2020 <sup>38</sup>	Zuo et al. 2020 <sup>39</sup>						
1. Were the criteria for inclusion in the sample clearly defined?			X							
2. Were the study subjects and the setting described in detail?	X	X	X							
3. Was the exposure measured in a valid and reliable way?										
4. Were objective, standard criteria used for measurement of the condition?										
5. Were confounding factors identified?			X	X						
6. Were strategies to deal with confounding factors stated?			X	X						
7. Were the outcomes measured in a valid and reliable way?	X									
8. Was appropriate statistical analysis used?	X	X	X	X						
<b>Total quality</b>	Poor	Poor	Moderate	Poor						

**Table 3**  
Adverse events among health care workers due to personal protective equipment use during the COVID-19 pandemic in the studies included in this systematic review

Reference	Any adverse event	Dry skin	Pressure injuries	Headache	Dermatitis	Allergy	Rash	Itching	Pain
Zhao et al. 2020 <sup>26</sup>	838 (87.3)	199 (20.7)		516 (53.8)	146 (15.2)	162 (16.9)	222 (23.1)		
Coelho et al. 2020 <sup>27</sup>	768 (69.4)		768 (69.4)						
Çağlar et al. 2020 <sup>28</sup>	208 (66.0)			115 (36.5)	64 (20.3)				
Tabah et al. 2020 <sup>29</sup>	2169 (80.0)		1088 (40.1)	696 (25.7)					
Jiang et al. 2020 <sup>30</sup>	1844 (42.8)		1293 (30.0)						
Hu et al. 2020 <sup>31</sup>	58 (95.1)	15 (24.6)	42 (68.9)			7 (11.5)	10 (16.4)	17 (27.9)	7 (11.5)
Ong et al. 2020 <sup>32</sup>	128 (81.0)			128 (81.0)					
Metin et al. 2020 <sup>33</sup>	473 (90.1)	473 (90.1)			379 (72.5)	100 (19.1)	100 (19.1)		
Guertler et al. 2020 <sup>34</sup>	34 (85.0)	32 (82.1)	13 (32.5)		6 (15.0)	8 (20.5)		12 (30)	
Yildiz et al. 2020 <sup>35</sup>	507 (91.7)	507 (91.7)		410 (74.1)					494 (89.3)
Singh et al. 2020 <sup>36</sup>	29 (67.4)	16 (37.2)	11 (25.6)	27 (62.8)	17 (39.5)	3 (7.0)	21 (48.8)	29 (67.4)	
Battista et al. 2020 <sup>37</sup>	168 (90.8)				54 (29.2)			118 (63.8)	93 (50.3)
Lin et al. 2020 <sup>38</sup>	280 (74.5)	258 (68.6)							
Zuo et al. 2020 <sup>39</sup>	198 (49.0)	47 (11.6)	76 (18.8)				50 (12.4)	60 (14.9)	13 (3.2)
Reference	Hyperhidrosis	Dyspnoea	Others						
Zhao et al. 2020 <sup>26</sup>		593 (61.8)	Skin squeeze; 598 (62.3), dizziness; 555 (57.8), maceration; 142 (14.8), conjunctivitis; 61 (6.4), extreme exhaustion; 598 (62.3)						
Coelho et al. 2020 <sup>27</sup>									
Çağlar et al. 2020 <sup>28</sup>		79 (25.1)							
Tabah et al. 2020 <sup>29</sup>	1266 (46.7)		Extreme exhaustion; 412 (15.2)						
Jiang et al. 2020 <sup>30</sup>			Skin tears; 86 (0.2), moisture-associated skin damage; 465 (10.8)						
Hu et al. 2020 <sup>31</sup>			Skin desquamation; 6 (9.9), moisture-associated skin damage; 16 (26.2)						
Ong et al. 2020 <sup>32</sup>									
Metin et al. 2020 <sup>33</sup>	75 (14.3)		Stomatitis; 100 (19.1), acne; 207 (39.4)						
Guertler et al. 2020 <sup>34</sup>	5 (12.5)		Asthma; 3 (7.5)						
Yildiz et al. 2020 <sup>35</sup>			Constipation; 145 (26.2), urine-related problems; 225 (40.7), nutritional disorders; 257 (46.5), sleep disorders; 309 (55.9), dehydration; 439 (79.4)						
Singh et al. 2020 <sup>36</sup>	37 (86.1)		Acne; 5 (11.6), nausea; 5 (11.6)						
Battista et al. 2020 <sup>37</sup>		136 (73.5)	Sneezing; 92 (49.7), acne; 79 (42.7), panic attack; 17 (9.2), ocular symptoms; 83 (44.9)						
Lin et al. 2020 <sup>38</sup>			Maceration; 199 (52.9), erythema; 227 (60.4)						
Zuo et al. 2020 <sup>39</sup>			Discomfort; 90 (22.3), erythema; 51 (12.6), burning; 15 (3.7)						

Values are expressed as n (%).

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**Table 4**  
Meta-analysis for the adverse events among health care workers due to personal protective equipment use during the COVID-19 pandemic

Adverse event	No. of studies	Pooled prevalence	95% confidence interval	I <sup>2</sup>	P value for the Hedges Q statistic
Dry skin	8	54.4	25.4 – 81.8	99.60	<.001
Pressure injuries	7	40.4	27.7 – 53.8	99.12	<.001
Headache	6	55.9	35.8 – 75.0	99.32	<.001
Dermatitis	6	31.0	11.1 – 55.5	99.09	<.001
Allergy	5	16.4	13.2 – 19.8	47.76	.105
Rash	5	21.4	15.1 – 28.5	90.04	<.001
Itching	5	39.8	16.2 – 66.3	97.62	<.001
Pain	4	35.5	0.3 – 88.1	99.73	<.001
Hyperhidrosis	4	38.5	15.3 – 64.9	98.98	<.001
Dyspnoea	3	53.4	27.2 – 78.6	98.81	<.001

dental professionals has revealed moderate breathing difficulties due to the use of filtering facepiece respirators, while the prolonged duration of respirators usage was related to headaches. This finding is confirmed by a study<sup>46</sup> that was conducted during the SARS pandemic and found that 37.3% of HCWs who were filtering facepiece respirators developed headaches. This percentage was even higher (81%) in a study<sup>32</sup> that was conducted during the COVID-19 pandemic and found also that the odds of headache were 4.2 times higher in HCWs with pre-existing headache than among those without a pre-existing headache. Likelihood of developing headache was greater among HCWs with a long-term utilization of filtering facepiece respirators.<sup>32</sup> Prolonged use of filtering facepiece respirators could result in hypercapnia and hypoxemia which led to headache.<sup>31</sup>

Seven studies<sup>27-30,32,38,39</sup> in our review found that the duration of PPE use is an important risk factor for adverse events among HCWs. The literature comes to an agreement with this finding since Lim et al.<sup>46</sup> during the SARS pandemic revealed that the increased duration of filtering facepiece respirator use is related to headaches development, while Shenal et al.<sup>48</sup> found a relation between prolonged wear of respiratory protection and discomfort. Also, longer wearing time of filtering facepiece respirators, surgical masks and goggles compress cheeks, ears, nose bridge, and forehead which could be the main cause of skin and pressure injuries on the head and face.<sup>71</sup> Additionally, the longer the wearing time of PPE items, the more the sweaty with heavy sweating stimulates the skin causing redness, itching and pain.<sup>30</sup> The problem is further complicated by the increased consecutive days with PPE leading to more adverse skin effects among HCWs.<sup>26,28</sup> Moreover, increased exposure to confirmed or suspected COVID-19 patients is related to increased wearing time of PPE because of the contagiousness of SARS-CoV-2.<sup>26,33,38</sup> In light of the above situations, daily wearing time of PPE items among HCWs should be decreased to protect them and avoid the adverse impact of PPE use.

Filtering facepiece respirators are more likely to cause adverse events such as breathing difficulties, headaches, panic attacks, and pressure related symptoms especially in case of prolonged use.<sup>31,32,37,46,55,70</sup> Also, Ong et al.<sup>32</sup> found that face shields cause headaches due to pain, pressure or compression from this PPE, while Battista et al.<sup>37</sup> found that face shields cause several symptoms, for example, nasal/facial pain, redness zygoma and nosebridge, and auricular pain. Moreover, head itching was more common among HCWs wearing caps,<sup>37</sup> while skin related symptoms (eg, dry skin, itching, and rash) were more frequent in case of HCWs with latex gloves.<sup>31</sup>

Our study has several limitations introducing bias. First, 10 out of 14 included studies were conducted in Asia and thus further studies should be performed worldwide, allowing us to generalize the results. Also, quality of studies was poor (in 9 studies) or moderate (in 5 studies), while adverse events were more frequent in studies

with poor quality compared to those with moderate quality. There is a need to perform more valid studies since studies with poor quality may inflate the results. In the same way, the fact that the assessment of adverse events was self-reported in 13 out of 14 studies may introduce information bias that exaggerates the frequency of adverse events. This bias could be eliminated with a clinical diagnosis of adverse events due to PPE use. Variability in study designs and populations introduces high heterogeneity in our meta-analysis. We applied a random effect model and we performed subgroup and meta-regression analysis to overcome this issue. We searched six databases and the reference lists of the studies included in our review but always there is a probability to omit relevant studies. Data regarding the factors that were related to a greater risk of adverse events were scarce and only 6 studies used multivariable analysis to eliminate confounders. Also, causal inferences between risk factors and adverse events are impossible since all studies were cross-sectional. Thus, studies with more appropriate design (eg, cohort studies and case-control studies) and more sophisticated analysis should be conducted to infer more valid results regarding risk factors for adverse events due to PPE use.

## CONCLUSION

In conclusion, the frequency of adverse events among HCWs due to PPE use is very high, while there are several sociodemographic, clinical and job risk factors for these events. The COVID-19 pandemic continues to threaten public health, and adverse events frequency and severity among HCWs may get worse. PPE among HCWs is imperative to avoid the widespread diffusion of SARS-CoV-2 but could be harmful due to the long-term utilization. Thus, organizations worldwide should publish guidelines for the appropriate PPE use to prevent these adverse events especially in countries with PPE shortages. Healthcare facilities should take the necessary precautions and change the working conditions during the COVID-19 pandemic (eg, regular breaks, shorter shifts, adequate supply of PPE, air-conditioning, prophylactic dressing, better material, proper fitting masks, and reduction in wearing time of PPE) to prevent adverse events associated with PPE use and minimize harm to HCWs. Creating a secure and safe work environment for HCWs could lead to better management of the COVID-19 pandemic and an increase in work performance. Since skin reactions are the more frequent adverse events, policy-makers should pay attention to skin hygiene and skin protection including use of skin or sealant protector, protection of injured areas, no use of oily products, wipe of skin to remove sweat, and removal of the masks as frequent as possible. HCWs' training about appropriate PPE use and knowledge of skin hygiene is of utmost importance. HCWs should recognize symptoms and signs of initial tissue damages adopting then preventive measures to

**Table 5**  
Factors related with a greater risk of adverse events among health care workers due to personal protective equipment use during the COVID-19 pandemic in the studies included in this systematic review

Reference	Factors	Level of analysis
Zhao et al. 2020 <sup>26</sup>	<ul style="list-style-type: none"> <li>- Older age (<math>P= .016</math>)</li> <li>- Nurses and physicians vs others (<math>P&lt; .05</math> in both cases)</li> <li>- Increased exposure to confirmed or suspected COVID-19 patients (<math>P&lt; .001</math>)</li> <li>- Increased consecutive days with PPE (<math>P= .001</math>)</li> </ul>	Univariate
Coelho et al. 2020 <sup>27</sup>	<ul style="list-style-type: none"> <li>- Younger age (OR:0.61; 95% CI:0.46-0.81, <math>P= .001</math>)</li> <li>- No use of prevention inputs (OR:69.7; 95% CI:22.1-219.5, <math>P&lt; .001</math>)</li> <li>- Longer duration of shifts wearing PPE (&gt;6 hours), (OR:1.84; 95% CI:1.35-2.50, <math>P&lt; .001</math>)</li> </ul>	Multivariable
Çağlar et al. 2020 <sup>28</sup>	<ul style="list-style-type: none"> <li>- Overweight/obese HCWs (BMI <math>\geq 25</math> kg/m<sup>2</sup>), (OR:1.79; 95% CI:1.06-3.03, <math>P= .029</math>)</li> <li>- Smokers (OR:1.93; 95% CI:1.04-3.59, <math>P= .037</math>)</li> <li>- Increased consecutive days with PPE (OR:1.41; 95% CI:1.22-1.64, <math>P&lt; .001</math>)</li> <li>- Longer duration of shifts wearing PPE (OR:1.38; 95% CI:1.11-1.73, <math>P= .004</math>)</li> </ul>	Multivariable
Tabah et al. 2020 <sup>29</sup>	<ul style="list-style-type: none"> <li>- Longer duration of shifts wearing PPE (OR:1.24; 95% CI:1.18-1.30, <math>P&lt; .001</math>)</li> </ul>	Univariate
Jiang et al. 2020 <sup>30</sup>	<ul style="list-style-type: none"> <li>- Male gender (OR:1.54; 95% CI:1.11-2.13, <math>P= .008</math>)</li> <li>- Heavy sweating (OR:119.48; 95% CI:87.52-163.11, <math>P&lt; .001</math>)</li> <li>- Longer duration of shifts wearing PPE (OR:2.27; 95% CI:1.61-3.21, <math>P&lt; .001</math>)</li> <li>- Higher grade of PPE (OR:1.47; 95% CI:1.08-2.01, <math>P= .014</math>)</li> </ul>	Multivariable
Hu et al. 2020 <sup>31</sup>	<ul style="list-style-type: none"> <li>- Female gender (<math>P&lt; .05</math>)</li> <li>- Younger age (20-29 years), (<math>P&lt; .05</math>)</li> </ul>	Univariate
Ong et al. 2020 <sup>32</sup>	<ul style="list-style-type: none"> <li>- Pre-existing primary headache diagnosis (OR:4.20; 95% CI:1.48-15.40; <math>P= .03</math>)</li> <li>- Longer duration of shifts wearing PPE (&gt;4 hours), (OR:3.91, 95% CI:1.35-11.31, <math>P= .012</math>)</li> </ul>	Multivariable
Metin et al. 2020 <sup>33</sup>	<p>Dermatitis</p> <ul style="list-style-type: none"> <li>- Female gender (OR:3.20; 95% CI:2.12-4.82, <math>P&lt; .001</math>)</li> <li>- Increased exposure to confirmed or suspected COVID-19 patients (OR:1.66; 95% CI:1.09-2.51, <math>P&lt; .001</math>)</li> <li>- Increased washing (OR:1.64; 95% CI:1.11-2.43, <math>P= .014</math>)</li> </ul> <p>Acne</p> <ul style="list-style-type: none"> <li>- Female gender (OR:3.08; 95% CI:2.01-4.70, <math>P&lt; .001</math>)</li> <li>- Younger age (<math>\leq 30</math> vs. <math>&gt; 30</math> years, OR:2.78; 95% CI:1.93-4.02, <math>P&lt; .001</math>)</li> </ul> <p>Allergy</p> <ul style="list-style-type: none"> <li>- Female gender (OR:2.17; 95% CI:1.27-3.72, <math>P= .005</math>)</li> <li>- Increased exposure to confirmed or suspected COVID-19 patients (OR:1.70; 95% CI:1.04-2.77, <math>P= .034</math>)</li> <li>- Diabetes mellitus (OR:4.52; 95% CI:1.65-12.36, <math>P= .003</math>)</li> </ul> <p>Stomatitis</p> <ul style="list-style-type: none"> <li>- Increased exposure to confirmed or suspected COVID-19 patients (OR:1.70; 95% CI:1.04-2.77, <math>P= .034</math>)</li> <li>- Diabetes mellitus (OR:3.47; 95% CI:1.56-9.56, <math>P= .016</math>)</li> </ul>	Univariate
Yildiz et al. 2020 <sup>35</sup>	<ul style="list-style-type: none"> <li>- Female gender (<math>P= .002</math>)</li> <li>- Younger age (<math>P= .001</math>)</li> </ul>	Univariate
Lin et al. 2020 <sup>38</sup>	<ul style="list-style-type: none"> <li>- Female gender (OR:1.87; 95% CI:1.04-3.39, <math>P= .038</math>)</li> <li>- Working in hospitals with a more severe epidemic (OR:2.41; 95% CI:1.41-4.11, <math>P= .038</math>)</li> <li>- Increased exposure to confirmed or suspected COVID-19 patients (OR:2.44; 95% CI:1.37-4.37, <math>P= .003</math>)</li> <li>- Longer duration of shifts wearing PPE (&gt;6 hours), (OR:4.26; 95% CI:1.99-9.12, <math>P&lt; .001</math>)</li> </ul>	Multivariable
Zuo et al. 2020 <sup>39</sup>	<ul style="list-style-type: none"> <li>- Higher grade of PPE (OR:2.63; 95% CI:1.30-5.40, <math>P= .009</math>)</li> <li>- Longer duration of shifts wearing PPE (4-8 hours vs &lt;4, OR:1.8; 95% CI:1.1-3.0, <math>P= .02</math>, &gt;8 hours vs &lt;4, OR:2.7; 95% CI:1.5-4.7, <math>p&lt;0.001</math>)</li> </ul>	Multivariable

BMI: body mass index; CI: confidence interval; HCWs: health care workers; OR: odds ratio; PPE: personal protective equipment.

avoid more severe injuries. For example, dry skin and dehydration-induced dermatoses could be avoided with adequate hydration, while moisturizers could help to restore the integrity of skin barrier.

## SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at <https://doi.org/10.1016/j.ajic.2021.04.084>.

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