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Adverse Effects of Personal Protective Equipment Among Intensive Care Unit Healthcare Professionals During the COVID-19 Pandemic: A Scoping Review

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Review Article

Adverse Effects of Personal Protective Equipment Among Intensive Care Unit Healthcare Professionals During the COVID-19 Pandemic: A Scoping Review

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Abstract

Introduction: To avoid exposure to SARS-COV-2, healthcare professionals use personal protective equipment (PPE) while treating COVID-19 patients. Prior studies have revealed the adverse effects (AEs) of PPE on healthcare workers (HCWs); however, no review has focused on the AEs of PPE on HCWs in intensive care units (ICUs). This review aimed to identify the AEs of PPE on HCWs working in ICUs during the COVID-19 pandemic.

Methods: A scoping review was conducted. MEDLINE, CINAHL, the World Health Organization (WHO) global literature on COVID-19, and Igaku-chuo-zasshi (a Japanese medical database), Google Scholar, medRxiv, and Health Research Board (HRB) open research were searched from January 25–28, 2021. The extracted data included author(s) name, year of publication, country, language, article title, journal name, publication type, study methodology, population, outcome, and key findings.

Results: The initial search identified 691 articles and abstracts. Twenty-five articles were included in the analysis. The analysis comprised four key topics: studies focusing on PPE-related headache, voice disorders, skin manifestations, and miscellaneous AEs of PPE. The majority of AEs for HCWs in ICUs were induced by prolonged use of masks.

Conclusion: The AEs of PPE among HCWs in ICUs included heat, headaches, skin injuries, chest discomfort, and dyspnea. Studies with a focus on specific diseases were on skin injuries. Moreover, many AEs were induced by prolonged use of masks.

Keywords

personal protective equipment, healthcare worker, intensive care unit, occupational health, COVID-19

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Healthcare professionals wear personal protective equipment (PPE) while treating COVID-19 patients to protect themselves from SARS-COV-2 exposure. However, prior literature has revealed adverse effects (AEs) of PPE on healthcare workers (HCWs) (Houghton et al., 2020). The AEs of PPE may cause reassignment of HCWs to non-COVID-19 wards (Hoernke et al., 2021). Additionally, PPE-related AEs may lead to inadequate use of PPE as well as increased chance of infection (Calò et al., 2020). Consequently, it may lead to loss of personnel to treat COVID-19 patients.

Clarifying knowledge regarding the AEs of PPE is crucial for the development of preventive measures and treatment. According to our knowledge, one systematic review (Houghton et al., 2020) reported several AEs of PPEs; however, there have been no systematic reviews focused on PPE-related AEs during the COVID-19 pandemic. We focused on the COVID-19 pandemic in this study, due to the global scale of the pandemic, the same root cause of infection, and use of similar PPE.

In this scoping review, we collected and systemically charted the available literature on PPE-related AEs and identified gaps in the existing knowledge. We found that nurses and other HCWs working in the ICU are at a high risk of infection as aerosol-generating procedures are more frequent (Díaz-Guio et al., 2020). Moreover, HCWs in the ICU are required to wear PPE in the patient room as well as in the patient area (World Health Organization, 2020). Further, a previous report revealed that HCWs in ICUs continuously wear PPE for a median of four hours (Tabah et al., 2020). Therefore, we focused on HCWs working in ICUs as they are at high-risk of PPE-related AEs.

Methods

Study Design

We conducted a scoping review using the methodological framework of Arksey and O'Malley (2005). Further, we presented the results using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA ScR) (Tricco et al., 2018). The PRISMA ScR checklist is presented in Online Appendix 1. The primary research question was: How does PPE affect HCWs' physical health, including pressure areas on the face, heat symptoms, and headaches in the ICU, during the COVID-19 pandemic? This scoping review was registered on the Open Science Framework (osf.io/4ac6f).

Eligibility Criteria

We developed key inclusion criteria based on the "population-concept-context" framework recommended by the Joanna Briggs Institute for scoping reviews (Peters et al., 2020). The population included healthcare professionals, the concept was the effect of PPE on physical health status, and the context was the ICU during the COVID-19 pandemic. We included studies on PPE-related physical and physiological changes and AEs on physical health that were published before January 25, 2021. We excluded psychological effects and infections in healthcare professionals. We included studies on healthcare professionals working in the ICU; however, we also included studies with hospital and ICU staff data. Articles published in academic journals and studies, comprising both quantitative and qualitative research and reviews, were included. To capture the most recent findings, we included pre-print studies, editorials, commentaries, and letters. No language restrictions were applied.

Literature Search Strategies

The following databases were searched on January 25, 2021: MEDLINE via PubMed, CINAHL, the WHO global literature on COVID-19, and Igaku-chuo-zasshi (a Japanese medical database). The key search terms used to identify potentially relevant studies are listed in Online Appendix 2. We also conducted a non-systematic search with preprint servers such as medRxiv and Health Research Board (HRB) open research to identify pre-published studies on January 28, 2021. Additionally, a non-systematic search was also conducted using Google Scholar. All non-systematic searches were conducted by three authors (AT, TU, and JT). We attempted to identify additional relevant studies by manually searching the reference lists of studies identified through the search as well as the articles citing those studies (based on Google Scholar). Two of the six (TU, HS, TF, AT, JT, and AO) reviewers independently screened the titles and abstracts of all articles to identify potentially relevant studies. Two of the three reviewers (TU, HS, and AO) independently assessed eligibility based on a full-text review. Disagreements were resolved by discussion, and, if necessary, a third person was brought in for arbitration.

Data Charting and Summarizing Data

The data charting form was developed by two researchers to determine which variables were extracted. The data were extracted by six reviewers (HS, RS, AO, TK, NH, and YW) using a pre-specified data charting form. The extracted data included author name(s), year of publication, country, language, article title, journal name, publication type, study methodology, population, outcome, and key findings. The extracted data were categorized into topics through discussion. We summarized

our findings through classification by outcome-focused topics in a narrative format. All authors participated in and agreed on this classification.

Ethics

Ethical approval and patient consent were not required.

Results

Study Selection and Characteristics

The initial search identified 691 articles and abstracts. A total of 25 articles were included in this study. The flow diagram is presented in Online Appendix 3. We included 12 cross-sectional studies (Bharatendu et al., 2020; Çağlar et al., 2020; Hajjij et al., 2020; Heider et al., 2021; Jiang, Liu, et al., 2020; Jiang, Song, et al., 2020; Ong et al., 2020; Ramanan et al., 2020; Swaminathan et al., 2020; Tabah et al., 2020; Unoki et al., 2020; Xia et al., 2020), three case reports (Chiriac et al., 2020; Dell'Era et al., 2020; Lam et al., 2020), three reviews (Downie, 2020; Gefen & Ousey, 2020; Gross et al., 2021), including a systematic review, two observational studies (Abiakam et al., 2021; Choudhury et al., 2020) including a study combined with a point prevalence study, a retrospective study (He et al., 2020), two qualitative studies (Begerow et al., 2020; Hoernke et al., 2021), and two letters without cases or data (Goh et al., 2020; Wiwanitkit, 2020). Participants of seven studies were exclusively HCWs working in the ICUs; however, participants of the remaining studies included HCWs working in the ICU. Several PPE-related AEs were reported in the included studies.

Research Key Topics

The summarized findings of the included articles are presented in Table 1. Of the 25 studies included in this review, 11 articles (Begerow et al., 2020; Çağlar et al., 2020; Choudhury et al., 2020; Gross et al., 2021; He et al., 2020; Hoernke et al., 2021; Ramanan et al., 2020; Swaminathan et al., 2020; Tabah et al., 2020; Unoki et al., 2020; Xia et al., 2020) reported miscellaneous PPE-related AEs using qualitative and quantitative methods. They reported prevalence with or without risk factors for extreme exhaustion, headaches, thirst, heat, pressure areas, retroauricular pain, chest discomfort, and dyspnea. Five articles investigated specific symptoms, such as PPE-related headaches (Bharatendu et al., 2020; Goh et al., 2020; Hajjij et al., 2020; Ong et al., 2020) and voice disorders (Heider et al., 2021). Nine studies reported PPE-related skin injuries and manifestations (Abiakam et al., 2021; Chiriac et al., 2020; Dell'Era et al., 2020; Downie, 2020; Gefen & Ousey, 2020; Jiang, Liu, et al., 2020; Jiang, Song, et al., 2020; Lam et al., 2020; Wiwanitkit, 2020). After conceptual classification, we concluded that the studies covered four key topics: PPE-related headaches, voice disorders, and skin injuries and/or manifestations, and miscellaneous AEs of PPE. The prevalence of each adverse effect in the ICU is summarized in Table 2.

Miscellaneous Adverse Effects

Eleven articles described miscellaneous, nonspecific PPE-related AEs, including two articles with qualitative methods(Begerow et al., 2020; Hoernke et al., 2021). Six studies (Çağlar et al., 2020; Ramanan et al., 2020; Swaminathan et al., 2020; Tabah et al., 2020; Unoki et al., 2020; Xia et al., 2020) conducted a cross-sectional survey and an article conducted retrospective cross-sectional survey (He et al., 2020) on the AEs of PPE. One international study (PPE-SAFE study) showed that 80% of HCWs working in the ICU reported significant AEs, including heat (51%), thirst (47%), pressure areas (44%), and headaches (28%) (Tabah et al., 2020). Another study conducted using the same methodology in a Japanese ICU revealed that heat was the most common adverse effect (75.2%), followed by pressure areas (56.1%), thus indicating that the nurse's position was an independent risk factor for significant heat symptoms (Unoki et al., 2020). Similarly, the same methodology of the PPE-SAFE study's methodology (Tabah et al., 2020) was applied to Australian ICU settings (Ramanan et al., 2020). The study found that 49% HCWs that experienced PPE-related AEs reported that the prevalence of pressure areas and headaches was 17% and 10%, respectively.

A Chinese study conducted a cross-sectional survey focusing on discomfort, including physical and psychological effects among HCWs in Wuhan, including ICU staff (22.9%) (Xia et al., 2020). Reported discomfort included retroauricular pain (81.8%), chest distress or dyspnea (78.5%), and dizziness or palpitations (42.1%). Another study employed a retrospective cross-sectional design focusing on the relationship between goggles and health in nurses (He et al., 2020). The study revealed that the most common goggle-related symptoms were headaches (79.1%), followed by nausea (46.8%). A study examining PPE-related physiological changes in ICU professionals reported a significant increase in heart rate and a decrease in perfusion index and oxygen saturation (Choudhury et al., 2020). The authors assumed that these physiological changes may lead to excessive exhaustion in ICU nurses after long shifts.

Table 1. Summarized Findings of Included Articles.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
Miscellaneous AEs	Tabah et al., 2020, International.	Personal protective equipment and intensive care unit healthcare worker safety in the COVID-19 era (PPE-SAFE): An international survey	Cross-sectional, web-based survey. 2711 HCWs working in the ICU.	AEs of PPE Heat (51%) Thirst (47%) Pressure areas (44%) Headaches (28%) Inability to use the bathroom (27%) Extreme exhaustion (20%) Pressure areas were associated with longer duration of shifts wearing PPE.
	Unoki et al., 2020, Japan.	Personal protective equipment use by healthcare workers in intensive care unit during the COVID-19 pandemic in Japan: Comparative analysis with the PPE-SAFE survey	Cross-sectional, web-based survey. 460 HCWs working in the ICU.	AEs of PPE Heat (75.2%) Thirst (32.2%) Pressure areas (56.1%) Headaches (12.2%) Inability to use the bathroom (27.6%) Exhaustion (43.0%) Feeling of intense heat is the most significant adverse effect, especially for nurses, despite short-duration PPE use.
	Ramanan et al., 2020, Australia.	Protecting healthcare workers during the COVID-19 pandemic: Australian results from the PPE-SAFE survey	Cross-sectional, web-based survey. 211 HCWs, of whom 95% (200) HCWs working in the ICU.	AEs of PPE Thirst (28%) Pressure areas (17%) Headaches (10%) At least one adverse effect was reported by 49%.
	Xia et al., 2020, China.	The physical and psychological effects of personal protective equipment on health care workers in Wuhan, China: A cross-sectional survey study	Cross-sectional, web-based survey. 279 HCWs, out of which 22.9% (68) HCWs working in the ICU.	AEs of PPE Mask pressure related retroauricular pain (81.8%) Chest distress and dyspnea (78.5%) Thirst (60.3%) Dizziness or palpitations (58.9%) Micturition cravings (55.6%) Nausea or vomiting (42.1%) Pressure sores on their faces (58.3%): nose (81.0%), cheek (66.5%), forehead (45.1%), and retroauricular areas (43.6%). Glove related skin damage (51.9%): eczema (59.1%), dry skin (57.8%), and skin erosion (53.9%).

(continued)

Table 1. Continued.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
				Pressure ulcers were significantly more common among HCWs who worked in PPE for more than four hours.
	Çağlar et al., 2020, Turkey.	Symptoms associated with personal protective equipment among frontline health care professionals during the COVID-19 pandemic	A single-center, cross-sectional survey. 175 HCWs working in the ICU or Pandemic Ward out of 315 HCWs.	AEs of PPE Headache (36.5%) Breathing difficulty-palpitation (25.1%) Dermatitis (20.3%) The risk factors of PPE related symptoms Extended use of PPE (OR = 1.41, 95%CI 1.22–1.64) Prolonged PPE use(OR = 1.38, 95%CI 1.11–1.73) Smoking (OR = 1.93, 95%CI1.04– 3.59) Overweight (OR = 1.79, 95%CI 1.06–3.03)
	Swaminathan et al., 2020, United Kingdom.	Impact of enhanced personal protective equipment on the physical and mental well-being of healthcare workers during COVID-19	A single-center, cross-sectional, web-based survey. 72 HCWs including ICU staff.	Exhaustion with a VAS core of more than 7 (70.8%) Headache with a VAS score of more than 7 (61.4%) Mask-related skin changes with a VAS score of more than 7 (43.2%)
	Choudhury et al., 2020, India.	Physiological effects of N95 FFP and PPE in healthcare workers in COVID intensive care unit: A prospective cohort study	Prospective observational cohort study. 75 HCWs working in the ICU (53 were doctors, 21 nurses, and 1 ICU technician)	AEs of PPE Fogging (100%) Headache (90.67%) Tiredness (70.67%) Difficulty in breathing (60%) Mask soakage (24%) PPE breach (4%) Palpitation (2.67%) Bronchospasm (1.13%) Fatigue and dyspnoea scores were both worse. Physiological changes associated with the use of PPE Increase in heart rate post-doffing from the baseline Decrease PI and SpO_2 post-doffing from the baseline.

(continued)

Table 1. Continued.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
	He et al., 2020, China.	The impact of goggle-associated harms to health and working status of nurses during management of COVID-19	Questionnaire-based retrospective study. 231 HCWs including ICU staff.	Goggle associated symptoms Headache (79.1%) Skin injury (I-IV stages) (66.2%) Dizziness (49.4%) Nausea (47.9%) Dysphoria (37.2%) Vomit (22.1%) Rash (10.4%) Claustrophobia (5.2%). The underlying reasons included tightness of goggles, unsuitable design, and uncomfortable materials.
	Begerow et al., 2020, Germany.	Perceptions of intensive care nurses during the COVID-19 pandemic: A qualitative survey	Qualitative study, content analysis using web-based questionnaires. 397 ICU nurses.	Six categories were identified. "struggle for PPE" was one of the six categories. This category included nurses' complaints of headaches and dyspnea.
	Hoernke et al., 2021, United Kingdom.	Frontline healthcare workers' experiences with personal protective equipment during the COVID-19 pandemic in the UK: A rapid qualitative appraisal	A rapid qualitative appraisal study. 46 HCWs, media reports and government PPE policies.	HCWs described PPE to be exhausting and uncomfortable to wear. Tight masks caused facial pain, marks and bruises, rashes, dry skin as well as difficulty in breathing, headaches, and irritability. Full-length gowns were hot and sweaty, causing overheating and dehydration.
	Gross et al., 2021, Germany.	COVID-19 and healthcare workers: A rapid systematic review into risks and preventive measures	A rapid systematic review with 38 studies.	Systematic review found that four studies reported PPE related skin injury and one study reported headache related to PPE.
Headaches	Ong et al., 2020, Singapore.	Headaches associated with personal protective equipment - A cross-sectional study among frontline healthcare workers during COVID-19	A single-center, cross-sectional survey. 158 HCWs including ICU staff	De-novo headaches related to PPE (82%). The risk factors for headaches Preexisting headache diagnosis (OR = 4.20, 95% CI 1.48–15.40) Combined use of N95 respirator and eyewear for >4 hours per day (OR 3.91, 95% CI 1.35–11.31)
	Bharatendu et al., 2020, Singapore.	Powered Air Purifying Respirator (PAPR) restores the N95 face mask induced cerebral hemodynamic alterations among	Cross-sectional study. 154 HCWs including ICU staff.	De novo headaches related to N95 respirator (80%) Physiological changes associated with donning of N95 respirator Increase in MFV (4.4 ± 10.4 cm/s, $p < .001$)

(continued)

Table 1. Continued.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
		healthcare workers during COVID-19 outbreak		Increase in ET-CO2 (3.1 ± 1.2 mmHg, $p < .001$) Decrease in PI (0.13 ± 0.12; $p < .001$) Donning PAPR and N95 respirator together showed normalization of PI, accompanied by normalization of ET-CO_2 values within 5 min.
	Hajjij et al., 2020, Morocco.	Personal protective equipment and headaches: Cross-sectional study among Moroccan healthcare workers during COVID-19 pandemic	Cross-sectional, web-based survey. 155 HCWs including ICU staff.	Headache related to PPE (62%) Being a physician and working for more than 12 hours were correlated with aggravated headache.
	Goh et al., 2020, Singapore.	Headaches due to personal protective equipment during COVID-19 pandemic: A Comment	Comment on. N/A.	The authors suggested that the development of de-novo headaches among frontline healthcare workers was related to the use of PPE.
Voice disorders	Heider et al., 2021, Chile.	Prevalence of voice disorders in healthcare workers in the universal masking COVID-19 era	A single-center, cross-sectional survey. 221 HCWs, of whom 53.6% (118) HCWs were working in the ICU.	Self-perceived voice disorder during the universal masking Mild symptoms (21.56%) Moderate or severe symptoms (11.10%) Abnormal score of VHI-10 questionnaire (26.24%)
Skin injuries and manifestations	Abiakam et al., 2021, United Kingdom.	Personal protective equipment related skin reactions in healthcare professionals during COVID-19	One point prevalence study and multicenter prospective study 108 ICU staff (one point prevalence study) and 307 HCWs in ICU and HCU	Changes in skin health after their shift (66%) Adverse skin reactions related to PPE (88%) The bridge of the nose was the most common affected site; however, various sites were affected. Higher average daily time PPE wearing was associated with higher frequency of manifestation of skin adverse reactions.
	Jiang, Song, et al. 2020, China.	The prevalence, characteristics, and prevention status of skin injury caused by personal protective equipment among medical staff in fighting	Cross-sectional, web-based survey. 4306 HCWs including ICU staff.	Overall skin injuries related to PPE (42.8%) Co-skin injuries (2 or more types of injuries) (27.4%) Multiple location injuries (76.8%) The risk factors of skin injury related to PPE

(continued)

Table 1. Continued.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
		COVID-19: A multicenter, cross-sectional study		Sweating (OR = 119.48, 95%CI 87.52–163.11) Daily wearing time (OR = 2.27, 95%CI 1.61–3.21) Male (OR = 1.54, 95%CI 1.11–2.13) Grade 3 PPE (OR = 1.47, 95%CI 1.08–2.01)
	Jiang, Liu, et al. 2020, China.	The prevalence, characteristics, and related factors of pressure injury in medical staff wearing personal protective equipment against COVID-19 in China: A multicenter cross-sectional survey	Cross-sectional, web-based survey. 4306 HCWs including ICU staff.	Overall skin injuries related to PPE (30.03%) Nose bridge (24.43%) Cheeks (23.46%) Auricle (20.32) Forehead (10.98%) Other (1.09%) The risk factors of skin injuries related to PPE Sweating (OR = 43.99, 95% CI 34.46–56.17) Male (OR = 1.50, 95% CI 1.12–1.99) Level 3 PPE (OR = 1.44, 95% CI 1.14–1.83) Longer wearing time (OR = 1.28, 95% CI 0.97–1.68)
	Chiriac et al., 2020, Romania.	Flare-up of Rosacea due to face mask in healthcare workers during COVID-19	Case report. 1 HCWs working in the ICU.	A case of flare-up of rosacea in a nurse working in an ICU, using FFP1 type mask at work and textile or paper mask outside the hospital.
	Dell'Era et al., 2020, Italy.	Nasal pressure injuries during the COVID-19 Epidemic	Case report. 1 physician working in the ICU.	A case of nasal pressure injuries (Stage II) from continuously wearing a N95 respirator for 6 hours over the previous 7 days.
	Lam et al., 2020, Malaysia.	N95 respirator associated pressure ulcer amongst COVID-19 health care workers	Letter with case report. 5 HCWs working in the ICU.	This study described a series of 5 HCWs with pressure ulcers (Grade 1–5) over the dorsum of the nose following prolonged usage of the N95 respirator.
	Wiwanitkit, 2020, India.	N95 respirator, COVID-19, and health care worker	Letter. N/A	The authors point out that complications from using PPE are rarely mentioned in the literature.
	Gefen & Ousey, 2020, Israel.	Prevention of skin damage caused by the protective	Narrative review N/A	This narrative review included four studies on skin injuries related to PPE. ICU HCWs and HCWs felt the mildest facial

(continued)

Table 1. Continued.

Type of AEs	Author, year, study location	Study title	Methodology and population	Intervention/Important results
		equipment used to mitigate COVID-19		skin abrasion, itching or burning sensation.
	Downie, 2020, Bahrain.	COVID-19 skin damage challenges: A brief review	Narrative review N/A	The authors discussed skin damage related to PPE. Many staff in ICU who wore a high level of PPE experienced PPE related skin injury.

Note. AE, adverse effect; PPE, personal protective equipment; HCWs, healthcare workers; ICU, intensive care unit; COVID-19, coronavirus disease-2019; OR, Odds ratio; CI, Confidence interval; SpO_2, Saturation of Peripheral Oxygen; VAS, Visual Analogue Scale; PAPR, Powered Air-Purifying Respirator: ET-CO_2, end-tidal carbon dioxide: PI, pulsatility index: MFV, mean flow velocity: VHI-10, voice handicap Index-10 questionnaire.

Headaches

Four articles discussed PPE-related headaches (Bharatendu et al., 2020; Goh et al., 2020; Hajjij et al., 2020; Ong et al., 2020). Two studies investigated the prevalence and risk factors (Hajjij et al., 2020; Ong et al., 2020), one was a letter of comment on a previous study (Goh et al., 2020), and one study suggested mechanisms and countermeasures (Bharatendu et al., 2020).

In one study, 128 of 158 (81.0%) HCWs experienced PPE-related de novo headaches when they wore a N95 respirator mask, either with or without protective eyewear (Ong et al., 2020). In another study that investigated PPE-related de novo or aggravated chronic headaches, 96 of 155 (62%) HCWs experienced headaches, of which 51 (32.9%) had de novo headaches and 45 (29%) had worsening chronic headaches (Hajjij et al., 2020). Wearing PPE for over 4 hours (Odds ratio [OR]: 3.91, 95% Confidence interval [CI], 1.35–11.31; $p = .012$) and pre-existing primary headache diagnosis (OR: 4.20, 95% CI, 1.48–15.40; $p = .030$) were identified as risk factors associated with PPE-related de novo headaches (Ong et al., 2020).

One observational study conducted in Singapore showed physiological changes in cerebral blood flow, pulsatility index (PI), and end-tidal carbon dioxide (ET-CO_2) while wearing PPE (Bharatendu et al., 2020). Donning of N95 respirator masks significantly increased mean flow velocity (4.4 ± 10.4 cm/s, $p < .001$), decreased PI (0.13 ± 0.12; $p < .001$), and increased ET-CO_2 (3.1 ± 1.2 mmHg ($p < .001$), suggesting that the elevated $PaCO_2$ led to increased cerebral blood flow, resulting in headaches. However, donning a powered air purifying respirator resulted in changes in PI and ET-CO_2 to the same level as the baseline.

Voice Disorders

One article described voice disorders as a side-effect of prolonged PPE use in HCWs in Chile, including ICU staff (Heider et al., 2021). Forty-seven of 218 (21.56%) HCWs reported mild symptoms, and 24 of 218 (11.10%) reported moderate or severe symptoms. Overall, nearly 33% HCWs noticed issues with their voices. The number of working hours, hours of mask daily use, and simultaneous mask use were independent variables associated with voice abnormalities.

Skin Injuries and Manifestations

Nine articles (Abiakam et al., 2021; Chiriac et al., 2020; Dell'Era et al., 2020; Downie, 2020; Gefen & Ousey, 2020; Jiang, Liu, et al., 2020; Jiang, Song, et al., 2020; Lam et al., 2020; Wiwanitkit, 2020) described PPE-related skin injury manifestations; however, these consisted of three original articles (Abiakam et al., 2021;

Table 2. Types and Frequency of Adverse Effects Related to PPE Among ICU HCWs.

Type of AE	Frequency of AEs	Reference
Heat	51–75%	Tabah et al. (2020), Unoki et al. (2020)
Thirst	28–47%	Tabah et al. (2020), Unoki et al. (2020), Ramanan et al. (2020)
Voice disorders	31.3%	Heider et al. (2021)
Fatigue/exhaustion	20–70.7%	Tabah et al. (2020), Choudhury et al. (2020)
Dyspnea/breathing difficulty	60.0%,	Choudhury et al. (2020)
Bronchospasm	1.1%	Choudhury et al. (2020)
Headache	10–90.7%	Tabah et al. (2020), Unoki et al. (2020), Ramanan et al. (2020), Choudhury et al. (2020)
Palpitations	2.7%	Choudhury et al. (2020)
Skin injuries and manifestations	17–56.1%	Tabah et al. (2020), Unoki et al. (2020), Ramanan et al. (2020)

Note. AEs, Adverse effects; PPE, Personal Protective Equipment; HCWs, Health care workers.

Jiang, Liu, et al., 2020; Jiang, Song, et al., 2020), three case studies (Chiriac et al., 2020; Dell'Era et al., 2020; Lam et al., 2020), a letter without data or cases (Wiwanitkit, 2020), and two brief reviews (Downie, 2020; Gefen & Ousey, 2020). All the studies and opinions focused on the use of masks. In particular, a study by Lam et al. (2020), which was based on a case-series study, emphasized that the N95 mask was associated with pressure ulcers at the bridge of the nose.

Jiang, Song et al. (2020) conducted a web-based cross-sectional survey using a convenience sample of 4308 respondents, comprising nurses and physicians, including ICU staff found that the prevalence of PPE-related skin injuries was 42.8% (95%CI: 41.30–44.30). Skin injuries were divided into three categories: device-related pressure injury (DRSI), moisture-associated skin damage (MASD), and skin tears (ST). The study revealed that skin injuries were most common in 42.8% HCWs in departments or wards, including the ICU. Additionally, the prevalence of DRSI, MASD, and ST was 30.0% (95%CI 28.69–31.41), 10.8% (95%CI 9.91–11.82), and 10.8% (95%CI 1.62–2.40) of those with skin injuries, respectively. Injuries were frequently observed at the bridge of the nose, cheeks, and ears (Jiang, Song et al., 2020). A one point prevalence study conducted with 108 HCWs working in an ICU and a high dependency unit revealed that the skin around the bridge of the nose (69%), ears (30%), cheeks (23%), and chin (20%) was affected, resulting in redness blanching, pressure damage, and itching (Abiakam et al., 2021). Lam et al. (2020) reported five HCWs working in ICUs with pressure ulcers at the bridge of the nose within two-week periods.

Discussion

To our knowledge, this is the first scoping review focusing on PPE-related effects in HCWs in intensive care units during the COVID-19 pandemic.

In this scoping review, we suggested that various AEs were common among HCWs providing care for COVID-19 patients. Our findings were similar to a previous systematic review (Houghton et al., 2020). While the median duration of continuous PPE wearing was four hours, Tabah et al. (2020) reported an increase of over 80% in the AEs of PPE if worn for more than three hours. This indicated that the AEs of PPE, including heat, pressure areas, skin manifestations, headaches, and exhaustion, are common for HCWs working in the ICU.

Our review clarified the dearth of data on the actual condition of PPE-related AEs in critical care settings in each country. The PPE-SAFE study (Tabah et al., 2020) was the largest international cross-sectional study; however, more than half of the respondents were from Europe. PPE-related adverse events were measured using web-based surveys worldwide and in some countries the same inventory was used (Ramanan et al., 2020; Tabah et al., 2020; Unoki et al., 2020). These surveys helped HCWs establish preventive strategies against the AEs of PPE. However, the factors influencing the frequency and characteristics of AEs include the pandemic situation, critical unit structure (i.e., presence of a COVID-19 dedicated ICU), ethnicity (i.e., shape of the nose) (Abiakam et al., 2021; Verberne et al., 2020), and the supply of PPE. In particular, the critical unit structure could be associated with the duration PPE use and the frequency of donning and doffing. For example, in a previous study (Unoki et al., 2020) conducted outside of Japan, COVID-19-dedicated ICUs were dominant (75%); however, they represented only 20% of such ICUs in Japan. Japanese respondents who reported significant thirst were 32.2%, while 47.4% of worldwide respondents reported this issue. Additionally, a recently published secondary analysis of the PPE-SAFE study in Italy (Ippolito et al., 2021) reported that the median time of wearing PPE continuously was 5 h (Interquartile range: 4–6 h). This finding was statistically significantly

higher than other countries. This could be because Italy was the first Western country to be severely impacted by COVID-19 and was therefore not prepared for a pandemic. Owing to these factors, the prevalence of PPE-related AEs differs among countries.

Additionally, the prevalence of AEs differed among professions. A previous study indicated that being a nurse was a risk factor for feeling significant heat while wearing PPE (Unoki et al., 2020). The authors speculated that as nurses had a higher level of activity than other professionals, they tended to feel significantly more heat due to PPE.

Studies on the effects of goggles on AEs in HCWs are rare. In this scoping review, only one study in China on the effects of goggles was included. Eye protection is essential to prevent exposure to SARS-CoV-2; however, there are alternatives to goggles, such as face shields and visors. In fact, 34.9% HCWs used goggles in an international study in April 2020 (Tabah et al., 2020). Thus, it is unlikely that there will be an increase in studies on AEs of goggles.

In this scoping review factors and pathophysiology for PPE-related headaches were studied. Headaches are one of the common PPE-related symptoms. This is an important issue because headaches may reduce concentration and decrease professional performance (Hajjij et al., 2020). N95 masks, rather than eye protection, seem to be associated with a de novo headache (Ong et al., 2020). N95 masks alter cerebral perfusion, which leads to headaches (Bharatendu et al., 2020). Moreover, long-term use of N95 mask was consistently an independent factor in the development or exacerbation of headache. We recommend that HCWs with headaches must avoid long shifts and be given opportunities to take off the N95 mask. This will help them maintain sufficient professional performance. Additionally, administrators and HCWs should be aware of the effect of headaches on professional performance as well as of the importance of taking off N95 masks. Further, a powered air-purifying respirator can be used to reduce headache symptoms (Bharatendu et al., 2020). A previous cross-sectional study indicated that headaches are associated with psychiatric distress (Chew et al., 2020). However, it was not able to show causal relationships for psychiatric distress because of its design. A prospective study is warranted to confirm causal relationships as detecting risk factors will facilitate risk reduction.

The harmful effects of N95 masks on voice disorders must be explored. Moreover, the N95 mask was shown to cause acoustic attenuation. A prior study demonstrated that the FFP2 mask combined with a face shield was responsible for up to 60.5% loss of speech intelligibility in noisy environments (Muzzi et al., 2021). Wearing masks makes it difficult for patients or colleagues to hear HCWs speaking; thus, they are required to speak louder than usual (Bandaru et al., 2020). This is also true for the elderly, who have various degrees of hearing loss and need to speak louder. A study in Chile suggested that about 30% HCWs including ICU staff noticed issues with their voice (Heider et al., 2021). The authors warned that HCWs are at risk of voice disorders during the COVID-19 pandemic. Little is known about voice disorders and PPE; thus, further investigation is required.

Skin injuries are a common and serious adverse effect of PPE. Skin injuries can cause pain and itching, increase the likelihood of clinicians touching their face, ears, and scalp, and may lead to risk of infection (Gefen & Ousey, 2020). Placing masks on the face inappropriately to reduce pain at open wound sites may also increase exposure to infection. Therefore, PPE-related skin injuries are an important concern for HCWs who treat COVID-19 patients. Lam et al. (2020) first reported that N95 masks were associated with pressure ulcers over the dorsum of the nose. In this review, many articles on skin injuries caused by N95 masks were included. Pressure from PPE may have the most substantial impact on PPE-related skin injuries. Moreover, the bridge of the nose and cheeks where the mask and goggles compress is most commonly affected by PPE (Abiakam et al., 2021; Jiang, Liu et al., 2020).

MASD was also reported in the included studies (Jiang, Song et al., 2020; Jiang, Liu et al., 2020). MASD is induced by prolonged water immersion, leads to hyperhydration of the stratum corneum, and is associated with the use of gloves and boots (Darlenski et al., 2021). MASD has also been investigated in patients (Woo et al., 2017). In fact, a previous study suggested that 23.8% of ICU patients had MASD. As there have been few studies regarding MASD for HCWs, especially focusing on those in the ICU, further studies are required on this topic.

Other types of PPE-related skin injuries can be caused by combined effects of using multiple devices, such as pressure on the ears from mask straps and goggles, and the forehead from face shields and surgical caps (Jiang, Liu et al., 2020). However, many studies have investigated skin injuries caused by the overall PPE and not on a device-by-device basis (Jiang, Song et al., 2020; Jiang, Liu et al., 2020). In these studies, being male, level 3 PPE, higher average daily time of PPE use (especially >4 hours), frequency of PPE relief, and heavy sweating were reported to be independent factors for PPE-related skin injuries (Abiakam et al., 2021; Jiang, Song et al., 2020; Jiang, Liu et al., 2020). However, there have been few studies on the prevalence of PPE-related skin injuries in HCWs working in ICUs. Further research is needed to clarify skin injury factors for each device because a combination of pressure, moisture, and shear can cause or prevent PPE-related skin injuries, especially in the area of intensive care.

Strengths and Limitations

This study has extensively collected and reviewed literature on AEs of PPE during the COVID-19 pandemic, with no language restrictions. Moreover, the literature gathered includes a broad coverage, comprising preprint servers. We believe that this scoping review will extend the understanding of PPE-related AEs and contribute to future research.

However, this review also has several limitations. We attempted to focus on HCWs working in the ICU; however, few studies have exclusively sampled HCWs working in the ICU. Therefore, our review may not be specific to ICUs. Additionally, we also searched through letters and preprint servers to find extensive studies. In particular, the studies retrieved from the preprint server are pre-peer-reviewed and the final papers may vary. Therefore, the results of this review may be inaccurate. However, we believe that the results of these studies will not change significantly post peer review. Moreover, the included studies have been conducted in different parts of the world, and differences in the timing and magnitude of the spread of infection, health care resources, and health care systems may have influenced the type and incidence of PPE-related AEs.

Implications for Clinical and Future Research

PPE-related AEs are common among HCWs. Further, health and hospital administrators must monitor AEs and provide appropriate education (Wiwanitkit, 2020) as well as protective agents.

Due to diversity in ICU structural designs and admission policies among countries, the actual condition of AEs of PPE should be examined; specifically, a cross-sectional study should be conducted in each country or region. Additionally, manufacturers should consider different shapes of N95 masks according to sex and ethnicity to prevent mask-related skin injuries. Moreover, research or systematic reviews on AEs as well as preventive and treatment measures to counter them are strongly warranted.

Conclusion

There were various PPE-related AEs for HCWs working in the ICU, the majority of which were induced due to prolonged use of masks. To ensure adequate use of PPE, preventive measures to counter these AEs are warranted.

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Author Contributions

Design of the work: T. U., H. S., T. F., A. T., J. T., N. I., and Y. S.; search and screening: T. U., H. S., T. F., A. T., J. T., A. O.; data extraction and charting: H. S., R. S., A. O., T. K., N. H., Y. W.; summarizing data and interpretation; T. F., T. U., H. S., R. S., A. O.; drafting the work; T. U., H. S., R. S., A. O., and T. K.; critique and revising the draft: all authors. All authors approved the final version for submission.

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Supplemental Material

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