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Personal Protective Equipment to Prevention of COVID-19 in Health Workers: A Review

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Review Article

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ABSTRACT

Introduction: The safety of health workers who provide care to patients with COVID-19 has not been ensured by all care institutions. The lack of availability of personal protective equipment contributes to creativity, new inventions and technological adaptations of protection, and also to greater exposure of health workers.

Objective: To identify in the scientific literature the personal protective equipment presented for the safety of health workers with regard to COVID-19.

Method: Review study with data extraction in six electronic sources published in the period from January to May 2020. The selection of studies, as well as the extraction of data, took place independently through the efforts of two researchers. The studies were classified as product and process technologies, and if they were evaluated and/or tested with research.

Results: We identified 2,177 articles, of which 12 were included in this review. Most of the personal protective equipment identified was for respiratory protection, followed by face contact and body contact protections. We noted that 58.3% of the articles dealt with product technology and 41.7% with process technology. Technologies were evaluated by highlighting the protection of health workers.

Conclusion: The technological propositions demonstrate possibilities for the safety of health workers with regard to COVID-19.

INTRODUCTION

The exponential spread of the virus that causes Coronavirus Disease 2019 (COVID-19) boosted the production and evaluation of health technologies, mainly regarding the protection in terms of preventing contamination of personnel. Therefore, Health Workers who are on the front line for combating, controlling and preventing the pandemic should be ensured with Personal Protective Equipment (PPE) [1].

The supply of emergency PPE demand has required new technological production processes, retrofitting and inventions worldwide [2]. Accordingly, this is a global need [3]. In the pertinent literature, technologies are presented as a new product or integrated within a care process [4].

In the context of the COVID-19 pandemic, there are several settings for patient care where the worker can be exposed and, consequently, become ill [5]. Therefore, it is an institutional and professional duty to prevent the cross-transmission of the virus, observing the official recommendations on PPE, in the potential means of transmission, whether the inhalation of the virus and/or the contact with infected individuals or contaminated surfaces [6].

Compiling the different technological proposals for the protection of the Health Worker, and also those developed in different contexts, and which are used in patient care, suspected or confirmed COVID-19 case, constitutes contributions about the safety of the Health Worker. Accordingly, the defined objective for this study was to identify the personal protective equipment aiming at the safety of the health worker with regard to COVID-19 in the scientific literature.

LITERATURE REVIEW

Review study performed in six steps:

1. Identification of the problem/selection of the guiding question;
2. Research in electronic literature;
3. Peer review of data;
4. Grouping and analysis of data;
5. Interpretation of results;
6. Presentation/report of the review [7].

The research was guided by the following question:

What are the personal protective equipment identified in the pertinent literature for the safety of health workers, published between January and May 2020? We used the PICo strategy, where P refers to the problem (health worker safety during patient care); I, interest of the study (personal protective equipment); Co, context (inpatient unit, pre-hospital care or transport - land or air).

Concerning the electronic searches of publications, we selected five databases, in addition to searches in Google Scholar, restricted to the first three pages. Therefore, they were as follows: National Library of Medicine (PubMed) to access the Medical Literature Analysis and Retrieval System Online (MEDLINE); Virtual Health Library (VHL) and Scientific Electronic Library Online Brazil (SciELO Brazil). In addition, we accessed the SCOPUS and Web of Science (WOS) databases using the platform of the Coordination for the Improvement of Higher Education Personnel (CAPES, as per its Portuguese acronym). The recovery in all bases took place on June 3rd, 2020.

As for the collection, we chose terms indexed in the Medical Subject Headings (MeSH) as “MeSH terms” and “All Fields”; and in the Descritores em Ciencias da Saúde (DeCS) as descriptors and synonyms, with variations in three languages (English, Portuguese and Spanish). We used the Boolean operators “AND” and “OR” to draw up the search strategy, adapted to each database. **Figure 1** shows the personalized strategy in PubMed.

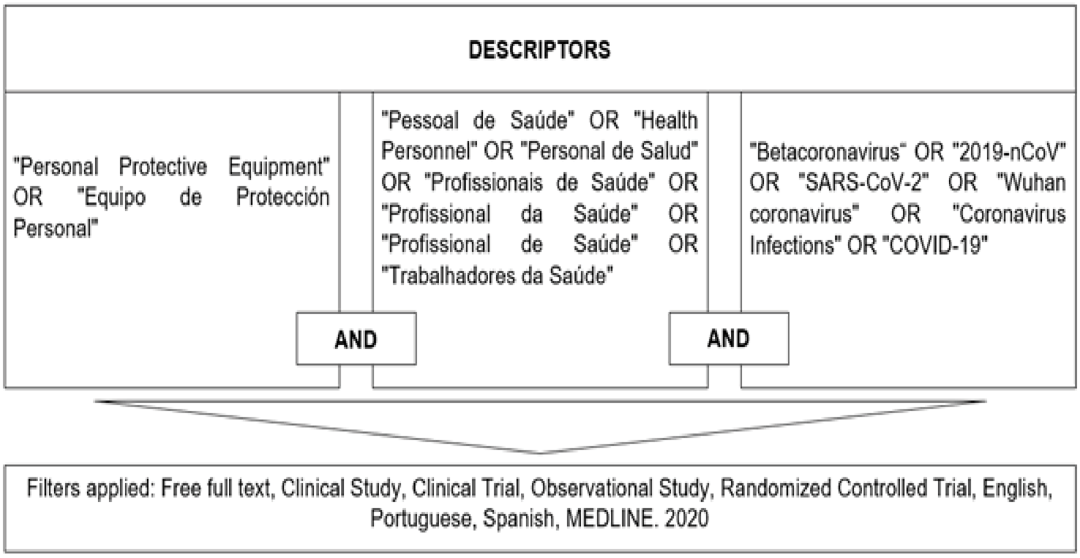

Figure 1. Search strategy on the National Library of Medicine (PubMed), with a combination of controlled descriptors, Boolean operators and filters. Florianopolis, Santa Catarina, Brazil, 2020.

The inclusion criteria: Studies performed in the context of hospital care, pre-hospital care or transport, land or air; original studies; randomized clinical trial (RCT), quasi-experimental studies, cohort studies, case-control studies, time series, interrupted time series, case series, case reports; technological reports, technical reports, epidemiological studies, as well as other studies that dealt with PPE with an outcome in the safety of the health worker during the care to the confirmed or suspected patient in COVID-19 cases; in English, Portuguese or Spanish; published from January to May 2020. The exclusion criteria were: editorials, integrative and systematic reviews, qualitative studies; studies that evaluated workers other than the health sector; and studies that addressed only collective protective equipment.

The recovered publications were exported to the reference management program, EndNote®, basic version, with a view to identifying duplicates and delete them. Subsequently, titles and abstracts were screened by two researchers, independently, in order to select those eligible for the study, according to the inclusion and exclusion criteria. This step was performed using an electronic tool - Rayyan® [8]. The resolution of selection conflicts was carried out by a third researcher.

We applied the Kappa coefficient to analyse the level of agreement between the pair of researchers. In this study, the following classification was adopted: less than 0.00, 'poor agreement'; 0.00 - 0.20, 'slight agreement'; 0.21 - 0.40, 'reasonable agreement'; 0.41 - 0.60, 'moderate agreement'; 0.61 - 0.80, 'substantial agreement'; and 0.81 - 1.00, 'almost perfect' [9].

A second evaluation was carried out, independently, by the pair of researchers, with the purpose of confirming the decision on the inclusion of the previously selected material. We performed, a thorough reading of the complete article, using the Rayyan® tool. A third researcher was in charge of resolving conflicts and, therefore, validating the final sample of included studies.

Data were extracted by a pair of researchers, independently, registered in a spread sheet drawn up in Microsoft Excel, version 2019. The following information was extracted: Identification of the first author and year, purpose of the study, place of the study (emergency unit, Intensive Care Unit [ICU], other inpatient units, land transport, air transport, pre-hospital care), country of study, collection period, study design, type of personal protective equipment, health worker, main results and conclusions.

Moreover, data were grouped into the following analytical groups, namely: 1. product technologies and process technologies [10-12]; 2. evaluated/tested product technologies and evaluated/tested process technologies.

Presentation of the review report took place through a narrative synthesis, as guided by the guidelines of the Synthesis without Meta-analysis (SWiM) [13]. In addition, main results were presented in the form of tables, graphs and according to the flowchart Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [14].

RESULTS AND DISCUSSION

In the six electronic databases consulted, we applied personalized filters, obtaining a total of 2,177 publications. This action took place following the selection steps, where the pair of researchers held the reading of titles and abstracts, whose decisions were paired and the Kappa coefficient was applied, thereby obtaining an agreement index of 0.68. We selected twelve articles that make up the corpus of analysis of this review. **Figure 2** presents the process of identification, screening and selection of articles.

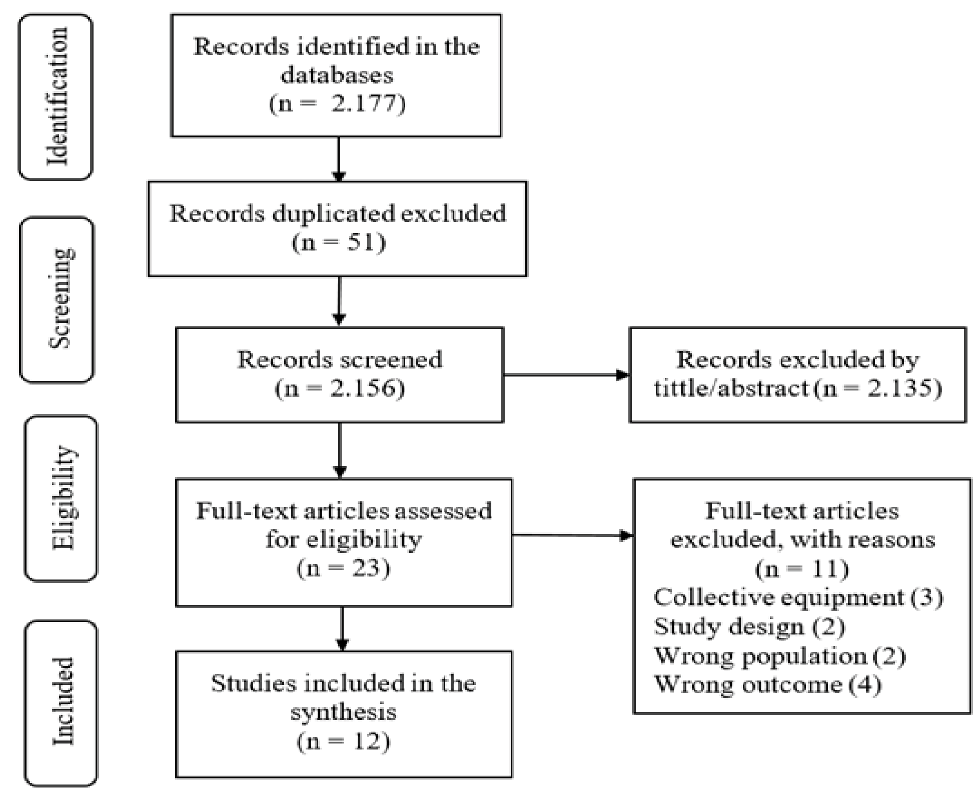

Figure 2. Flowchart of articles identified, screened and selected for inclusion in the review according to PRISMA [14]. Florianopolis, Santa Catarina, Brazil, 2020.

The articles included are presented in **Table 1**. All were published in English, two of which (16.7%) were performed in China; two (16.7%) in the United States of America and; two (16.7%) in Singapore. Each of the remaining six studies was developed in a country: Germany, Belgium, Canada, India, Italy and Pakistan. In addition, all studies were observational, six (50.0%) descriptive;

three (25.0%) analytical; two (16.7%) of technological adaptation; and one (8.3%) of technological proposition.

Table 1. Articles included in the review (n=12). Florianopolis, Santa Catarina, Brazil, 2020.

Author/Country	Study objective	Study location	Study design	Type of PPE	Health Worker	Main results
Chow et al. [15]/ China	To stratify the needs for face protectors when performing head and neck cancer surgeries, with the objective of preserving the PPE used by the professional during the COVID-19 pandemic.	Surgery room	Descriptive observational study	Face shield	Nurse/Doctor	There were 45 surgical procedures, droplet count per procedure was 57.8% for the surgery surgeon (n=26), 59.5% for the first assistant (n=22) and 8.0% for the second assistant (n=2). No droplets were observed in nurses' face shields (n=45). The droplet count was higher and more widespread during osteotomies. No splash of gout was observed in robotic surgery.
Convissar et al. [16]/United States	Construction of a face mask (MAVerIC) equivalent to the N95 mask from supplies available in a surgery room.	Unidentified	Observational descriptive study of technological adaptation	Face mask	Doctor	Using supplies that are available in a surgery room can demonstrate the construction of a safe and reusable face mask, capable of filtering 99.7% of particles equal to or greater than 0.3 microns in size instead of other PPE and can be adjusted to ensure there is no leak to optimize safety and effectiveness.
Delgado et al. [17]/Canada	To evaluate the reality and perceptions of personal safety among health professionals who practice it in Latin American countries during the current COVID-19 outbreak.	Latin America (online)	Analytical observational study	Gloves/Disposable apron/Surgical mask/N95 masks/Face shield	Nurse/Doctor/Other Health Workers	936 health professionals responded to the survey. Access to PPE was as follows: disposable gloves (n=853; 91.1%), disposable aprons (n=630; 67.3%), surgical masks (n=785; 83.9%), N95 masks (n=516; 56.1%) and face shield (n=305; 32.6%). The vast majority (n=707; 75.5%) had access to personnel safety policies and procedures.
Di Maio et al. [18]/Italy	To guide through a video, the step-by-step procedure to properly dress and undress PPE. To demonstrate its use and provide some technical notes on the execution of the nasopharyngeal and oropharyngeal swab for COVID-19.	Reserved room for collection of respiratory species, dressing of PPE and removal of PPE	Descriptive observational study	Gloves/disposable clothing/filter mask/surgical mask/Goggles/face shield or protective visor/shoe covers	Health Workers	The phase of removing the PPE is the procedure with the greatest risk of self-contamination for the health professional. Following the various steps shown in the video, there were no cases of contagion by SARS-CoV-2.
Khan et al. [19]/ India	To create an economical, simple and easy solution to prepare face protection masks to guide use as a safety barrier to prevent contact/exposure to the coronavirus.	Unidentified	Observational descriptive study of technological adaptation	Mask attached to face shield	Health Workers	Despite of being simple, the designed mask serves as a protective barrier and is more effective than no protection. It can be used in conjunction with the N95 mask, a simple disposable mask or a simple mask made of polyester fabric folded twice. These masks can be prepared by hospital staff within the hospital environment and can also be sterilized.
Malik et al. [20]/ Pakistan	To better understand the effectiveness and benefits of the different types of Respiratory Protection Equipment (RPE) used by health professionals when treating patients infected with coronavirus.	Intensive care unit	Descriptive observational study	Surgical mask/N95 mask	Health Workers	All 34 health professionals exposed to patients with coronavirus were isolated and quarantined for a period of 14 days. Half of the health professionals wore surgical masks, while the rest wore N95 masks. Two nasopharyngeal samples were obtained from health professionals on the day of exposure and on the last day of quarantine for the COVID-19 test through the PCR assay. Each health professional remained asymptomatic and tested negative for COVID-19 in both tests.

Ong et al. [21]/ Singapore	To evaluate safety during prolonged use of PPE and check the risk of contamination by SARS-CoV-2.	Isolation Wards	Descriptive observational study	Goggles/N95 masks/shoes	Nurse/Doctor/ Cleaner	All 90 samples from 30 health professionals were negative. The average time spent in the patient's room was 6 minutes: 8 minutes for doctors, 7 minutes for nurses and 3 minutes for the cleaning team. Activities varied according to personal contact (for example, medication administration or cleaning), to closer contact (for example, physical examinations and collection of respiratory samples).
Perkins et al. [22]/ United States	To explore the most feasible and safe methods to sterilize PPE for reuse	Surgery room retrofitted for an optimized environment to prevent the transmission of pathogens	Descriptive observational study	N95 mask	Health Workers	After collection, storage and safe decontamination of N95 respirators using hydrogen peroxide vapor, it was possible to immediately decontaminate the masks in a surgery room.
Swennen et al. [23]/Belgium	To present a proof of concept and a prototype of a reusable, personalized three-dimensional (3D) printed face mask, based on individual facial scanning, 3D modeling and 3D printing	Unidentified	Descriptive observational study	Custom 3D protective filter mask	Health Workers	3D facial scanning was performed using a smartphone and the file export took less than 2min and 30 seconds. The scanning procedure was safe. The authors emphasize that the clinical test of this prototype is essential before use in real situations, since the performance of the face mask depends not only on the filter used, but also on its individual adjustment to avoid leaks around the mask perimeter.
Wang et al. [24]/ China	To follow-up the presence of SARS-Cov-2 on surfaces in the hospital environment, sewage and PPE of teams in isolation wards.	Isolation Wards/ Isolation Intensive Care Unit	Descriptive observational study	Gloves/N95 mask	Health Workers	33 patients confirmed with COVID-19, 9 admitted to the ICU (7 patients with mechanical ventilation and 2 patients without mechanical ventilation); the other 24 patients were hospitalized in the other two isolation wards. All patients without mechanical ventilation wore surgical masks. The front surface of the N95 masks (5) and the gloves (4) of the teams in isolation wards were also negative for the SARS-CoV-2 RNA; accordingly, it was like all respiratory samples from the teams in the wards. The 36 samples of the environmental surface in isolation areas, including the clean area, the semi-contaminated area and the contaminated area, were negative. Three sewage samples from the pre-processing disinfection equipment entrances were positive for the SARS-CoV-2 RNA. Viral loads in respiratory and stool samples were confirmed for COVID-19.
Wesemann et al. [25]/Germany	To evaluate the use of 3D printers, which are used for dental purposes, produce face shields using open source design data and investigate their clinical suitability.	Intensive Care Unit	Analytical observational study	Face Shield	Nurse/Doctor	The filament weight (21-42 g) and the printing time (1: 40-3: 17h) differed significantly among the rooms. Similarly, adjustment, comfort, space for additional PPE and protection varied among designs. For clinical suitability, a chosen design must allow enough space for glasses and N95 respirators, in addition to maximum coverage of the facial area.

Ong et al. [26]/ Singapore	To determine the risk factors associated with the development of headaches associated with the new PPE, as well as the perceived impact of these headaches on personal health and job performance.	Isolation Wards/ Emergency Rooms/ Medical Intensive Care Unit	Analytical observational study	N95 mask/ Goggles	Nurse/Doctor/ Paramedical team	158 health professionals took part in the study, 128 developed headaches associated with the new PPE. Those based in the emergency department had a longer average daily duration of combined PPE exposure compared to those working in isolated wards or medical ICUs. Since the COVID-19 outbreak, 42/46 (91.3%) of respondents with a pre-existing diagnosis of headache "agreed" or "strongly agreed" that the increased use of PPE has affected the control of their headaches, thereby affecting their performance level.
PPE: Personal Protective Equipment, ICU: Intensive Care Unit						

Professionals, nurses and doctors were the health workers most cited in the studies. Other workers were also identified, occupational workers who carry out hygiene and cleaning activities in the health services environment. Health workers are all personnel who offer direct or indirect assistance to patients [5]. According to the Centers for Disease Control and Prevention (CDC), health personnel, even though they are not directly involved in patient care, are at risk of exposure to infectious agents that can be transmitted in the health care environment [5].

We observed that most studies were performed in isolation wards or ICUs. Based on experiences in China, hospital units can be divided into High Risk Units for Hospital Infection and Low Risk Units for Hospital Infection; the first group included emergency units, respiratory treatment, intensive care unit, surgical/anesthetic center, infectious diseases and clinical laboratory. The other hospital treatment units are classified as low risk for hospital infection [27]. Countries that have previously experienced viral spread and population illness possibly contribute to guide the management of patients in other parts of the world.

Isolation measures for patients infected with COVID-19 are extremely important due to the high respiratory virulence, although there is a lack of confirmation about transmission by contact. It is known that outside the human body it is possible for the virus to survive for up to 24 hours [28]. Therefore, isolation provides safety to health workers who recognize the need for the proper use of PPE, which complies with public health recommendations for mitigating its impact on the population [28].

Among PPE, equipment related to respiratory protection was identified in most studies: surgical mask, N95 mask, mask coupled with face shield, face mask with HEPA filter, 3D filter mask. Face protection equipment, such as safety glasses and visors, were also identified in the examined articles, with different forms of manufacture, design and possibility of use in conjunction with another PPE. These, in order to avoid transmission, are used to assist suspected or confirmed patients for COVID-19, due to the possibility of transmission through inhalation of droplets contaminated with the virus or contact with contaminated individuals or surfaces and subsequent contact with mucous membranes (ocular, nasal and buccal) [6].

Although the COVID-19 signs and symptoms are mainly respiratory, those affected by the virus may also have gastrointestinal, neurological symptoms, or even no symptoms [29-32]. Nevertheless, further investigations are needed to support the effectiveness of protection methods, which have been considered safe, given the possibilities of clinical manifestations of the disease and, therefore, new possibilities of transmission routes.

Table 2 shows the classifications of the studies according to the protection technology, type and the evaluation/test of the technology. Of the articles 58.3% (7) dealt with product technology and 41.7% (5) dealt with process technology. In two studies (16.7%) they did not test their products. In 58.3% of the studies, they evaluated the process technology highlighting the protection of health workers. Among the types of evaluations/tests with laboratory evaluation, applied in process technologies, we highlight protection for inhalation of droplets and/or aerosols during care practice; however, an evaluation of the interpretation of the decontamination process for PPE was also identified. Among the types of evaluations/tests applied in the product technologies, those focused on facial adjustment, safety and comfort stand out. In addition, product technology tests were performed outside the COVID-19 context; however, developed with a view to providing service within this reality.

Table 2. Classification of studies according to protection technology, type and technology evaluation/test. Florianopolis, Santa Catarina, Brazil, 2020.

Author/Year/Country	PPE	Type of Technology	Evaluation/technology test
Chow et al. (2020) [15]/ China	Face shield	Process	Splash protection in head and neck surgical procedure
Convissar et al. (2020) [16]/ United States	MAVerICK face mask (includes a mask, HEPA filter, elbow, fan circuit and head strap)	Product	Facial adjustment test
Delgado et al. (2020) [17]/ Canada	Gloves/Disposable apron/Surgical mask/ N95 masks/Face shield	Product	No evaluations/tests

Di Maio et al. (2020) [18]/ Italy	Gloves/disposable clothing/filter mask/ surgical mask/goggles/face shield or protective visor/shoe covers	Process	Protection during placement sequence, use for nasal swab collection and withdrawal sequence
Khan et al. (2020) [19]/India	Mask attached to face shield	Product	No evaluations/tests
Malik et al. (2020) [20]/ Pakistan	Surgical mask/N95 mask	Process	Protection during orotracheal intubation
Ong et al. (2020) [21]/ Singapore	Goggles/N95 masks/shoes	Process	Protection during vital signs measurement, physical examination, medication administration, collection of respiratory specimens, blood collection, communication, cleaning of the environment
Perkins et al. (2020) [22]/ United States	N95 mask	Process	Implementation of processes for collection and storage, pre-processing, hydrogen peroxide decontamination and post-processing of filter mask respirators.
Swennen et al. (2020) [23]/ Belgium	Custom 3D protective filter mask with membrane filter	Product	Boolean mathematical calculation of virtual adaptation. Protection during daily care routine in isolations
Wang et al. (2020) [24]/ China	Gloves/mask N95	Process	Protection during daily care routine in isolations
Wesemann et al. (2020) [25]/Germany	Facial shield	Product	Measurement of weight, time and material used, comfort, protection and additional space for another PPE
Ong et al. (2020) [26]/ Singapore	N95 mask/goggles	Process	Protection during daily care routine in isolations and headache with the use of PPE
PPE: Personal Protective Equipment			

Only one study addressed behavioural aspects with regard to the sequence of placement of the PPE, correct use and the sequence of withdrawal [18]. The purpose of using PPE is to prevent the microorganism from contaminating the worker, including parts of the body susceptible to infection, and, consequently, undermining its health [33]. However, in the world context, it is recognized that the incorrect handling of this equipment presents potential for contamination of workers. In an observational study, the presence of viruses in the hands under gloves, face, and apron under protective clothing of health workers indicated two possibilities: the PPE used did not offer complete protection as barriers and/or self-contamination happened during the disposal of PPE [33]. With regard to the new coronavirus, another possibility is the re-suspension of the virus load on the surface of health workers' clothing at the time of removal [34].

Technological proposals, adaptations and insertions in the work process raise important changes, especially in the emergency context of the pandemic caused by COVID-19. The virulence and rapid global spread of the new Coronavirus has changed the Public Health Emergency setting of International Interest [32]. In health services, the viral spread has been concerned not only by affecting patients, but also by workers who are continuously exposed to occupational risks [1]. Accordingly, the safety of those involved, even if indirectly, in the care environment, should not be overlooked, although little discussed in the pertinent literature.

PPE is a right of Health Workers, although some factors related to supplies have caused an overload on health services with regard to scarcity. The use of some of this equipment by the population, the erroneous and also irrational use of PPE, as well as the prospect of limited production in the long term, have contributed to the lack of adequate supply of these items [3]. Nevertheless, the technological production initiatives highlighted in the studies, especially technological adaptations from the available resources, present possibilities for overcoming the problem of lack and inadequate provision of PPE.

CONCLUSION

In the COVID-19 context, we identified initiatives to develop technologies, adaptations and tests during the study period. The emergency need configured by the pandemic has mobilized several public and private organizations for technological production and innovation regarding the safety of health workers.

The technological propositions of product and process present ideas and solutions for the managers of health services in the sense of overcoming the scarcity of material, either through innovation and the reuse of available resources. The results presented in this study contribute to the safety of health workers, showing different PPE and also the institutional availability and its disposal, as well as to the handling by workers who deal with PPE.

Finally, we should underline that the creation and/or innovation of PPE is not enough, as it is necessary to test its safety and proper use, in a systematic way in health services, especially in highly complex units, in pre-hospital care and in the means of inter-hospital transport. Therefore, it is essential to invest in the development of research with appropriate methods for evaluating products and processes, with regard to production, innovation, maintenance, disinfection and disposal, with an outcome in the safety of the health worker and, also, of society at large.

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