Universiteit Leiden
The Netherlands

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The role of gowns in preventing nosocomial transmission of respiratory viruses: a systematic review☆

L.M. Orsel [a], J.A. Severin [a], M. Knoester [b], M. Lokate [b], A. Voss [b], C. P. Haanappel [a], J.J.A. van Kampen [c], B.L. Haagmans [c], M.P.G. Koopmans [c], K. E. Veldkamp [d], R. van Mansfeld [e], H.J. de Jager [f], A.F. Voor in 't holt [a,*,†], C. Bowles [g,†]

[a] *Department of Medical Microbiology and Infectious Diseases, Erasmus MC University Medical Center, Rotterdam, The Netherlands*
[b] *Department of Medical Microbiology and Infection Prevention, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands*
[c] *Department of Viroscience, Erasmus MC University Medical Center, Rotterdam, The Netherlands*
[d] *Leiden University Center for Infectious Diseases — Medical Microbiology and Infection Prevention, Leiden University Medical Center, Leiden, The Netherlands*
[e] *Department of Medical Microbiology and Infection Prevention, Amsterdam University Medical Centers, Amsterdam, The Netherlands*
[f] *Centre for Infectious Disease Control, The National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands*
[g] *Department of Medical Microbiology, Radboud University Medical Center, Nijmegen, The Netherlands*

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SUMMARY

Background: During the COVID-19 pandemic, long-sleeved gowns were advocated as personal protective equipment for healthcare workers (HCWs). The purpose of gowns is preventing transmission of infectious agents via the uniform or arms during contact with patients and their surroundings. Gowns, however, entail a substantial burden; in costs, workload for HCWs, and generated waste.
Aim: To evaluate the current knowledge regarding the use of gowns during care of patients with COVID-19 and other respiratory viruses to prevent nosocomial transmission.
Methods: PRISMA guidelines were used to search five databases (Medline, Embase, Web of Science, Cochrane, Google Scholar) up to April 11th, 2023.
Findings: The search identified 2667 potentially relevant studies, of which 30 were selected and divided into four categories. In 12 studies, contamination rates of gowns ranged from 0% to 77.5% (median: 1.43%). Three out of seven studies showed that virus remained infectious the longest on Tyvek coveralls and plastic gowns, and the shortest on

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* Corresponding author. Address: Department of Medical Microbiology and Infectious Diseases, Erasmus MC University Medical Center, Dr Molewaterplein 40, 3015 GD Rotterdam, The Netherlands. Tel.: +31 657381619.
E-mail address: a.voorintholt@erasmusmc.nl (A.F. Voor in 't holt).

† These authors contributed equally to this manuscript.

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cotton and polyester. Two out of seven studies found a protective effect between HCW protective clothing and infection of HCWs. Finally, three out of four studies concluded that short sleeves, cotton gowns, or no gowns provided the same level of protection as standard gowns.

Conclusion: Viral RNA can be found on clothing, but it is unclear whether viruses are transmitted to HCWs and/or patients. Evidence for the protective effect of long-sleeved gowns over alternatives is still insufficient. Therefore, well-controlled and adequately powered laboratory transmission experiments that simulate real-life conditions are necessary.

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Introduction

Throughout history, respiratory viruses have posed a significant threat to public health. During the twentieth century, the world experienced three pandemics of influenza: Spanish influenza H1N1 in 1918, Asian influenza H2N2 in 1957, and Hong Kong influenza H3N2 in 1968 [1]. The first coronavirus epidemic, caused by SARS-CoV-1, happened at the start of the 21st century [2]. A couple of years later, a new influenza A H1N1 virus caused the 2009 pandemic [3], which was quickly followed by the next coronavirus epidemic, caused by MERS-CoV [2]. In March 2020, the COVID-19 outbreak, caused by SARS-CoV-2, was declared a pandemic [4].

Infection prevention and control (IPC) guidelines issued by national and international organizations recommended, among others, long-sleeved gowns as part of personal protective equipment (PPE) for healthcare workers (HCWs) [4]. The purpose of the gown is to prevent transmission via the uniform or arms when in direct contact with an infectious patient or their surroundings. It is estimated that in the first year of the pandemic, these recommendations resulted in the use of 24 million gowns in 0.5 million patient-days [5]. The burden of the use of gowns is great, both in costs, workload for HCWs, and amount of waste and laundry [6].

As of March 2024, long-sleeved gowns are still in international guidelines [7]. In the Netherlands, the guidelines were updated that same month to no longer recommend the use of long-sleeved gowns [8]. There is, however, no substantial evidence to support this change.

Discontinuation of an established IPC measure such as the use of long-sleeved gowns during care of patients with respiratory viruses should preferably only be done when patient and HCW safety is guaranteed. There is an urgent need for more evidence to guide such a decision. The aim of this systematic review was to collect and evaluate the current knowledge about the use of long-sleeved gowns during the care of patients with COVID-19 and other respiratory viruses to prevent nosocomial transmission. Additionally, the aim was to include evidence relating not just to long-sleeved gowns, but to all types of clothing worn by HCWs.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplementary file 1) [9]. The protocol was registered in the International Prospective Register of Systematic Reviews, also known as PROSPERO (registration number CRD42023423231).

Study selection

A comprehensive search of five electronic databases (Medline, Embase, Web of Science, Cochrane, Google Scholar) was performed on April 11th, 2023. All studies relevant to the research question were included, independent of country, language, study population, or study design. The complete search strategy, including a list of the applied search terms, can be found in Supplementary file 2.

Two reviewers, L.O. and A.V., screened the identified studies for relevance based on title and abstract, and assessed them for eligibility based on the full text. Any difference in opinion was resolved by discussion. The inclusion criteria used for the title and abstract selection were: (1) studies that discussed transmission from clothing sources in a healthcare setting, and (2) studies that discussed the role of gowns as a measure to prevent transmission of respiratory viruses in healthcare settings. For the full text selection, the following inclusion criteria were used: (1) studies that evaluated the use of long-sleeved gowns or other types of healthcare clothing during the care of patients with respiratory viruses, and (2) studies that compared the effect of different healthcare clothing types or materials on the transmission of respiratory viruses.

Studies not related to the subject, studies without an adequate description of the healthcare clothing or respiratory viruses that were studied, and reviews were excluded. However, the reference lists of potentially relevant reviews were screened to identify any studies that may have been missed during the initial database search, which in turn underwent the same screening and assessment process.

Data extraction

The identified studies were divided into four categories: (I) clothing sampled after patient care, (II) virus detection on clothing tested in a laboratory setting, (III) questionnaires about use of clothing and viral test results of HCWs, and (IV) different clothing types tested in a real or simulated healthcare setting. Data extraction forms were developed per category and filled out. The data was extracted by L.O. and checked by A.V. For each category, the title, author, year of publication, journal, city and country, article type, study

period, study design, and study setting were extracted. The extracted information regarding the methods and results differed per category (Supplementary file 3). The completed forms were sent to the corresponding authors, along with the request to check the data for correctness and to add any missing information. If the authors did not respond within two weeks, a reminder was sent out. All data, including potential corrections and additions, was collected in an Excel file.

Study quality

The methodological quality of the included studies was assessed using appropriate guidelines based on the study design. Cross-sectional and case—control studies were evaluated using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [10]. For crossover studies, the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement was applied [11]. For in-vitro studies, the MICROVI checklist was developed (Supplementary file 4). The studies were classified as either low (0—33.3% of the total applicable points), medium (33.4—66.7% of the total applicable points) or high (66.8—100% of the total applicable points) methodological quality. This quality assessment was not utilized to exclude studies.

Results

The search identified 2667 non-duplicate, potentially relevant studies (Figure 1). Seven additional studies were identified from reference list scanning of relevant reviews. The title and abstract screening selected 76 studies for eligibility assessment. From these 76 studies, 30 met the inclusion criteria and were included in this review and classified into the four above-mentioned categories (Figure 1). Thirteen authors (43.3%) responded to our request to verify the extracted data, and ten of those provided additional data.

Most of the studies were full research articles ($N = 20$); the remainder consisted of short reports ($N = 5$), letters to the editor ($N = 2$), research letters ($N = 2$), and a short communication ($N = 1$) (Table I). Sixteen studies (53.3%) were performed in Asia, nine (30.0%) in Europe, and five (16.7%) in North America. Half of these studies were cross-sectional studies ($N = 15$); the second largest group comprised in-vitro studies ($N = 7$) (Table I).

Category I: clothing sampled after patient care

In the first category, most of the 12 included studies focused on SARS-CoV-2, except one [12], which investigated three groups of other respiratory viruses (Table II). Across the studies, there were 18 experimental setups to test five different clothing types. For the purpose of this review, the term 'protective suits' was classified as coveralls (in all categories). A variety of HCWs participated in the studies; their contact with the patients ranged from 15 to 350 min. Most of the HCW activities were routine care activities, and one study included aerosol-generating procedures (AGPs) [13]. The patient populations had varying degrees of illness duration and severity. For sampling, most studies ($N = 6$) specified that they used swabs premoistened with transport medium, and the overall number of samples taken ranged from one to 133 per study. In all studies, polymerase chain reaction (PCR) was used for virus detection, and one study additionally performed virus isolation on positive samples [14]. The contamination rates (defined as samples testing positive by PCR) ranged from 0% to 77.5%, half of them being 0% (median: 1.43%; mean: 11.38%) (Table II). The most frequently contaminated area was the torso (79 out of 170 torso samples across all the studies; 46%). This was partly due to a high contamination rate (77.5%) found in one study set in a large COVID-19 ward, where HCWs spent 4 h among patients before providing 80 torso samples [15]. If we disregard this study, the most frequently contaminated areas were the torso (17/90; 19%), the sleeves (15/121; 12%), the hood (6/44; 14%), and the foot dorsum (5/34; 15%). Five studies reported the cycle threshold (C_T) values of their positive samples, with four describing all values >35, indicating a low viral load [13—17]. The study that performed additional virus isolation did not manage to successfully isolate infectious virus from the 11 reverse transcription (RT)—PCR positive samples.

Category II: virus detection on clothing tested in a laboratory setting

Six out of seven studies from this category focused on SARS-CoV-2, while the remaining study investigated influenza A virus (Table III) [18]. All studies had a similar setup: small pieces of clothing were inoculated with virus, after which attempts to detect the virus at specific time-points were made. The tested clothing included one apron, three coveralls, three gowns, three scrubs, two T-shirts and one sports shirt. All studies performed the experiments at room temperature; one additionally investigated the recovery of the virus at 4 °C and 37 °C [19]. The detection time-points varied between 10 min and 30 days. The most applied detection methods were a plaque assay or $TCID_{50}$ assay, both culture-based methods used for measuring the infectious viral titre. A haemagglutination assay and quantitative (q)RT—PCR were also performed by two separate studies [18,20]; however, only the results generated using culture-based methods were taken into account during the analysis of this category. Infectious virus could be detected up to 14 days after application (Table III). Viable SARS-CoV-2 remained detectable the longest on Tyvek coveralls (7 and 14 d) [21,22] and plastic gowns (6 d) [21]. SARS-CoV-2 infectivity became undetectable fastest on cotton (3 d and 4 h) [21,22], polyester (2.5 h) [21] and a combination of these two materials (4 h) [19]. Additionally, the combination of these two materials also performed the best in another study, where the least amount of infectious SARS-CoV-2 was recovered after 10 min from this combined material compared to cotton and polyethylene [23].

Category III: questionnaires about use of clothing and viral test results of HCWs

Four out of seven studies from the third category focused on SARS-CoV-2 [24—27]; the other three focused on SARS-CoV-1 (Table IV) [28—30]. The studies assessed the effectiveness of PPE in preventing HCWs from becoming infected, by questioning both infected and non-infected HCWs about the PPE they wore during care of positive patients. For the purpose of this review, only data evaluating the effectiveness of protective clothing was collected. The questionnaires were filled

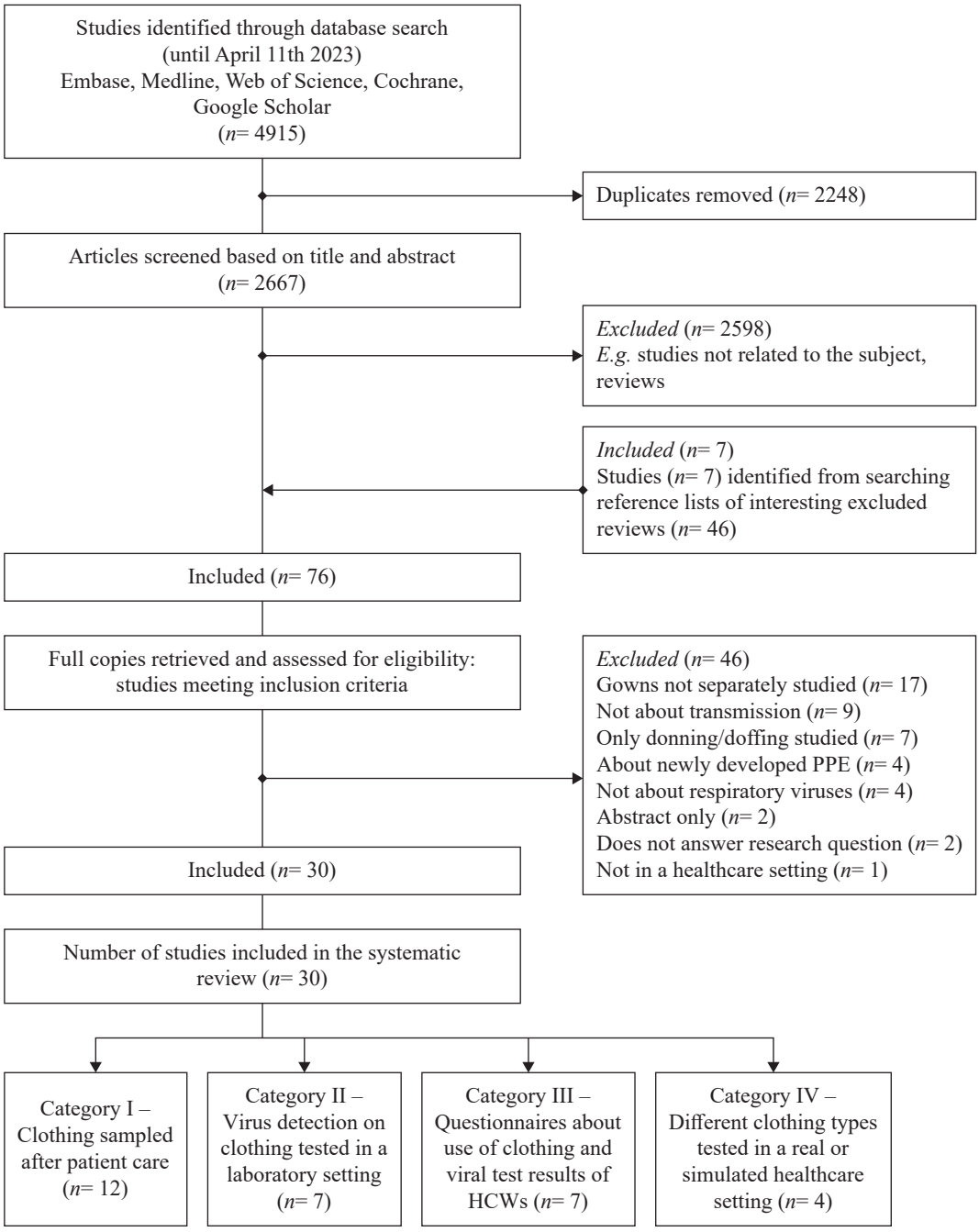

Figure 1. Flow diagram illustrating the study selection process for this systematic review. PPE, personal protective equipment; HCWs, healthcare workers.

in mostly by doctors and nurses, and the number of participants varied between 51 to 604 HCWs. The clothing types that were studied included gowns ($N = 6$), aprons ($N = 2$), and coveralls ($N = 2$). The percentage of HCWs who did not wear the indicated clothing during patient care ranged from 12.1% up to 100% in one study that investigated PPE breaches (Table IV) [24]. For SARS-CoV-2, only one study observed a significant effect between HCWs not wearing protective clothing and those same HCWs becoming infected after being exposed to SARS-CoV-2 patients at work [26]. This was only statistically significant when the HCWs performed general operations (not further specified), not when performing aerosol-generating procedures such as intubation. For SARS-CoV-1, one study found a significant effect between HCWs who did not wear a gown and HCWs who became infected [28]. However, this significance was not retained in multivariable analyses.

Category IV: different clothing types tested in a real or simulated healthcare setting

In the last category, two out of four studies simulated SARS-CoV-2 contamination with the use of a UV fluorescent

Table I
General characteristics of the included studies

Category	First author [reference]	Year of publication	Country	Article type	Study period	Study design	Study setting	Quality assessment
I	Aumeran [46]	2021	France	Letter to the editor	2020	Cross-sectional study	Infectious disease ward	High
I	Brandner [14]	2022	Germany	Full research article	January 2021 to May 2021	Cross-sectional study	3 clinical pathology departments and 1 department of legal medicine	High
I	Jung [47]	2020	South Korea	Letter to the editor	2020	Cross-sectional study	Medical centre with isolation rooms	Medium
I	Jung [13]	2021	South Korea	Short report	February 17th, 2021 to April 19th, 2021	Cross-sectional study	Tertiary care medical centre with single-patient isolation rooms	High
I	Ong [48]	2020	Singapore	Research letter	January 24th, 2020 to February 4th, 2020	Cross-sectional study	SARS-CoV-2 outbreak centre with isolation rooms	Medium
I	Peng [15]	2023	China	Full research article	April 30th, 2022, May 5th, 2022, and May 14th, 2022	Cross-sectional study	COVID-19 ward with 100 beds	High
I	Peyrony [16]	2020	France	Full research article	April 1st, 2020 to April 8th, 2020	Cross-sectional study	University hospital emergency department and 7-bed short stay unit	Medium
I	Phan [12]	2019	USA	Full research article	March 2017 to June 2017 and September 2017 to April 2018	Cross-sectional study	Acute care hospital with 465 beds	High
I	Shahi [49]	2022	UK	Short report	April 2020	Cross-sectional study	Large tertiary care acute hospital trust	Medium
I	Wei [50]	2020	China	Short report	March 4th, 2020 and March 12th, 2020	Cross-sectional study	Non-ICU isolation ward	Medium
I	Yao [17]	2023	China	Full research article	March 2022 to May 2022	Cross-sectional study	2 Fangcang shelter hospitals (500 and 1500 beds)	High
I	Yung [51]	2020	Singapore	Short report	2020	Cross-sectional study	Hospital isolation unit	Medium
II	Córdoba-Lanús [20]	2021	Spain	Full research article	September 2020 to December 2020	In-vitro study	Laboratory	High
II	Haddow [52]	2021	USA	Short report	Unknown	In-vitro study	Laboratory	High
II	Harbourt [19]	2020	USA	Full research article	January 2020	In-vitro study	Laboratory	High
II	Kasloff [22]	2021	Canada	Full research article	Unknown	In-vitro study	Laboratory	High
II	Paton [21]	2021	UK	Full research article	May 2020 to December 2020	In-vitro study	Laboratory	High
II	Sakaguchi [18]	2010	Japan	Full research article	Unknown	In-vitro study	Laboratory	Medium
II	Xue [23]	2022	UK	Full research article	June 2021	In-vitro study	Laboratory	High
III	Gaikwad [24]	2022	India	Full research article	June 2020 to February 2021	Cross-sectional study	COVID ward at tertiary care level hospital	High
III	Khalil [25]	2020	Bangladesh	Full research article	May 2020 to June 2020	Cross-sectional study	Multiple hospitals	Medium
III	Lai [26]	2020	China	Full research article	February 11th, 2020 to February 15th, 2020	Cross-sectional study	3 major tertiary teaching hospitals in Wuhan	High

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Table I (*continued*)

Category	First author [reference]	Year of publication	Country	Article type	Study period	Study design	Study setting	Quality assessment
III	Seto [28]	2003	China	Research letter	March 15th to March 24th	Case—control study	5 hospitals	High
III	Shimbashi [27]	2023	Japan	Full research article	August 2020 to November 2020	Case—control study	7 hospitals with COVID-19 outbreaks	High
III	Teleman [29]	2004	Singapore	Full research article	March 2003	Case—control study	Hospital	High
III	Yin [30]	2004	China	Full research article	April to May 2003	Case—control study	10 hospitals	Medium
IV	Dix [31]	2021	UK	Full research article	Unknown	Crossover study	Simulated intervention	Medium
IV	Farhat [33]	2021	Iran	Short communication	April 20 2020 to July 22 2020	Case—control study	Neonatal ICU	High
IV	Pelke [34]	1994	USA	Full research article	1987 to 1988	Crossover study	Neonatal ICU	Medium
IV	Vincent [32]	2022	UK	Full research article	Unknown	Crossover study	Simulated intervention in hospital ICU	High

ICU, intensive care unit.

substance [31,32] (Table V). The first compared the performance of three clothing sets in preventing contamination transfer [31]; the second compared long-sleeved gowns to short-sleeved gowns [32]. In these simulated healthcare settings, it was observed that, after final doffing, more UV fluorescent substance was found on the arms of HCWs who wore short sleeves. However, one of these studies concluded that short sleeves provided adequate protection, as long as hand and arm hygiene was performed. The remaining two studies occurred in real healthcare settings and focused on SARS-CoV-2 [33] and respiratory syncytial virus (RSV) [34] (Table V). In the SARS-CoV-2 study, HCWs wore cotton gowns instead of plastic gowns for three months, and the effect on the HCW infection rate was assessed. This study concluded that cotton gowns sufficiently protected the HCWs, as no HCW had become ill. The RSV study consisted of alternate two-month gowning and no-gowning cycles over a period of eight months and evaluated the effect on the infection rate in the patient population. This study found no significant differences in the infection rates between the gowning and no-gowning periods.

Study quality

Six studies from category I were ranked as being of high quality, together with six studies from category II, five from category III, and two from category IV (Table I). The other six studies from category I were classified as being of medium quality, together with one study from category II, two from category III, and two from category IV (Table I).

Discussion

The results from category I revealed that viral contamination was found on clothing worn by HCWs during patient care, albeit in varying proportions. In half of the experimental setups, no viral RNA could be retrieved from the clothing. The torso was the most contaminated area of clothing, even after the exclusion of the study of Peng *et al.* [15]. The only study from this category that included AGPs among their HCW activities concluded that these did not produce a significant difference in the contamination [13]. An important observation is that out of all the included studies, just half mentioned the days after symptom onset. This is, however, important information to determine the level of infectiousness of patients, as it has been shown that the detection of viral infectivity wanes faster than detection of viral RNA [35]. Additionally, across all studies mainly PCR results were reported, but the detection of viral RNA does not distinguish between infectious and non-infectious virus [35]. The only study from this category that performed both RT—PCR testing and viral culture was the study by Brandner *et al.*, which also reported the lowest C_T values at around 26.5 [14]. In this study autopsies were performed, which might require more intensive contact with the patient as opposed to standard care and could therefore result in a higher viral load compared to the other studies that reported C_T values >35. On the other hand, the viral culture in this study did not yield any positive results. It is therefore unclear whether the contamination found on the clothing contained viable virus.

The studies from category II proved that, *in vitro*, respiratory viruses could remain infectious on each of the tested

Table II
Study characteristics of studies belonging to category I: clothing sampled after patient care

Study	Patient population	No. of HCWs	Types of HCW (activities)	Contact time	Viruses studied (variant)	Clothing	Clothing area	Sample method	Amount of samples	Detection	% Contamination	Viral load
Aumeran [46]	6 COVID-19 patients (all PCR positive, moderate to critical chest computed tomography, 3–23 days after symptom onset, 5/6 coughing)	3 (+1 gown hung <50 cm from the patient for 24 h)	Physician (clinical examination), nurse (nursing care), physiotherapist (pulmonary rehabilitation)	Only specified for the 2 positive samples: nursing care 25 min, pulmonary rehabilitation 30 min	SARS-CoV-2	Non-woven long-sleeved gowns (manufacturer unknown)	Sleeves, chest (40 cm × 10 cm)	Dry swabs, 20 rubs per swab	42 (21 per clothing area)	Real-time RT–PCR	4.76% (2/21 sleeves, 0/21 chest)	C_T value from validation experiment: 33
Brandner [14]	11 autopsies of COVID-19 patients (PCR during hospital stay + rapid PCR or antigen test during autopsy)	22	Autopsy-conducting physician and autopsy assistant (full autopsies with opening of all body cavities)	25–150 min	SARS-CoV-2	Long-sleeved gown (Samco clinhand, Medline OPS) or coverall (ProSafe 2, Dupont Tyvek, Med-Comfort)	Back	Swabs (Copan) moistened with transport medium, swabbing ≥15 s	22 samples for PCR, 22 samples for virus isolation	Real-time RT–PCR and virus isolation	0.0% (0/22 PCR samples); no virus isolation performed	N/A
Brandner [14]	11 autopsies of COVID-19 patients (PCR during hospital stay + rapid PCR or antigen test during autopsy)	22	Autopsy-conducting physician and autopsy assistant (full autopsies with opening of all body cavities)	25–150 min	SARS-CoV-2	Plastic apron (Med-Comfort)	Chest	Swabs (Copan) moistened with transport medium, swabbing ≥15 s	22 samples for PCR, 22 samples for virus isolation	Real-time RT-PCR and virus isolation	50% (11/22 PCR samples); virus isolation unsuccessful	Median C_T value: 26.5
Jung 2020 [47]	2 mild COVID-19 patients (3–5 and 12–15 days after symptom onset)	19	Nurses (checking vital signs, administering oral medication, phlebotomy, and bedpan disposal)	4 h	SARS-CoV-2	Coveralls (manufacturer unknown)	Head, neck, wrist, abdomen, back, foot dorsum, sole	Aseptic premoistened swabs (Dacron) with viral transport medium, swabbing 15 times	133 (19 per clothing area)	PCR	11% (5/19 head, 5/19 foot dorsum, 3/19 sole, 1/19 wrist, 1/19 abdomen, 0/19 neck, 0/19 back)	Average 2.88 $\log_{10}$ copies/mL
Jung 2021 [13]	9 severe-to-critical COVID-19 patients (2–12 days after symptom onset)	15	Physicians (general care, physical examination, acquisitions of respiratory samples; AGPs were performed in 5 cases)	20 min (median)	SARS-CoV-2	Coveralls (UPC Ltd)	Head, neck, forearm, abdomen, foot dorsum, back, hip	Sterile premoistened swabs with viral transport medium (manufacturer unknown)	105 (15 per clothing area)	Real-time RT–PCR	2.86% (2/15 abdomen, 1/15 forearm, 0/15 head, 0/15 neck, 0/15 foot dorsum, 0/15 back, 0/15 hip)	C_T values abdomen: 38.62 and 37.91 (no AGPs), forearm: 37.91 (AGP; suctioning of airway)
Ong [48]	3 COVID-19 patients (4–11 days after symptom onset)	2	Physicians (activities unknown)	1 h	SARS-CoV-2	Gown (manufacturer unknown)	Upper front part, lower front part	Sterile premoistened swabs (manufacturer unknown)	4	Real-time RT–PCR	0.0%	N/A
Peng [15]	Unknown (100 beds)	Unclear (7 people on duty in contaminated area (ward), rotation every 4 h; 3 people on duty in clean area (outside of ward), rotation every 8 h)	Doctor, nurses, nursing assistants (routine medical operations)	4 h	SARS-CoV-2	Protective suit (manufacturer unknown)	Chest	Disposable cotton swab moistened with virus inactivation solution or saline (manufacturer unknown)	80	PCR	77.5% (62/80)	Average C_T values: 35.48
Peyrony [16]	7 COVID-19 patients	3	Nurses (patient care)	Unknown	SARS-CoV-2	Gown (care and advice)	Torso, arms	Sterile premoistened swabs with universal transport medium for viruses (Copan)	6 (3 per clothing area)	Real-time RT–PCR	16.7% (1/3 torso, 0/3 arms)	C_T value: 38.37
Phan [12]	52 (30 patients in droplet and contact isolation, 21 in droplet isolation, 1 in contact isolation). Influenza A ($N = 23$), influenza B ($N = 8$), rhinovirus ($N = 15$), parainfluenza ($N = 1$), coronavirus ($N = 1$), RSV ($N = 3$), adenovirus ($N = 1$).	59 (11 participated more than once, resulting in 72 sets of measurements)	Unknown (routine care)	3 h (uncertain)	3 groups: (1) influenza A/B; (2) rhinovirus; (3) other (RSV, parainfluenza, coronavirus)	Scrubs (manufacturer unknown)	Unknown	Swabs (Copan)	28	qPCR	11% (3/28)	150 copies/cm^2
Phan [12]	52 (30 patients in droplet and contact isolation, 21 in droplet isolation, 1 in contact isolation). Influenza A ($N = 23$), influenza B ($N = 8$), rhinovirus ($N = 15$), parainfluenza ($N = 1$), coronavirus ($N = 1$), RSV ($N = 3$), adenovirus ($N = 1$).	59 (11 participated more than once, resulting in 72 sets of measurements)	Unknown (routine care)	3 h (uncertain)	3 groups: (1) influenza A/B, (2) rhinovirus, (3) other (RSV, parainfluenza, coronavirus)	Gowns (manufacturer unknown)	Shoulders, cuffs	Swabs (Copan)	53	qPCR	21% (11/53) (positive areas unknown)	3.6×10^4 copies/cm^2
Shahi [49]	Unknown	12	8 nurses, 3 physiotherapists, 1	Area A (intubated patients in side rooms):	SARS-CoV-2	Gown (manufacturer unknown)	Forearms/arms	Viral liquid culture swabs in viral transport	5	Real-time PCR	0.0%	N/A

(*continued on next page*)

Table II (*continued*)

Study	Patient population	No. of HCWs	Types of HCW (activities)	Contact time	Viruses studied (variant)	Clothing	Clothing area	Sample method	Amount of samples	Detection	% Contamination	Viral load
			healthcare assistant (observation of vital signs, assisting patients with eating or mobilizing, moving equipment, performing ECGs, care of long lines, and monitoring ventilation and administering medications)	1.5 h; Area B (3–6-bedded bay): 30 –60 min; Area C (patients on oxygen or non-invasive ventilation in side rooms): 1–2 h				medium (manufacturer unknown)				
Shahi [49]	Unknown	12	8 nurses, 3 physiotherapists, 1 healthcare assistant (observation of vital signs, assisting patients with eating or mobilizing, moving equipment, performing ECGs, care of long lines, and monitoring ventilation and administering medications)	Area A (intubated patients in side rooms): 1.5 h; Area B (3–6-bedded bay): 30 –60 min; Area C (patients on oxygen or non-invasive ventilation in side rooms): 1–2 h	SARS-CoV-2	Apron (manufacturer unknown)	Front	Viral liquid culture swabs in viral transport medium (manufacturer unknown)	5	Real-time PCR	0.0%	N/A
Shahi [49]	Unknown	12	8 nurses, 3 physiotherapists, 1 healthcare assistant (observation of vital signs, assisting patients with eating or mobilizing, moving equipment, performing ECGs, care of long lines, and monitoring ventilation and administering medications)	Area A (intubated patients in side rooms): 1.5 h; Area B (3–6-bedded bay): 30 –60 min; Area C (patients on oxygen or non-invasive ventilation in side rooms): 1–2 h	SARS-CoV-2	Scrubs (manufacturer unknown)	Whole uniform	Viral liquid culture swabs in viral transport medium (manufacturer unknown)	5	Real-time PCR	0.0%	N/A
Wei [50]	9 mild COVID-19 patients (34–52 days after symptom onset)	8	Unknown (medical round, measuring vital signs, collecting clinical specimens, performing intravenous infusion, and delivering food)	Unknown	SARS-CoV-2	Isolation gowns (manufacturer unknown)	Outside surface (30 cm × 35 cm)	Sterile premoistened rayon swabs (Copan)	8 (unclear)	Real-time RT–PCR	0.0%	N/A
Wei [50]	9 mild COVID-19 patients (34–52 days after symptom onset)	8	Unknown (medical round, measuring vital signs, collecting clinical specimens, performing intravenous infusion, and delivering food)	Unknown	SARS-CoV-2	Protective clothing (manufacturer unknown)	Outside surface (30 cm × 35 cm)	Sterile premoistened rayon swabs (Copan)	8 (unclear)	Real-time RT–PCR	0.0%	N/A
Yao [17]	Unknown (500 and 1500 beds)	10	Administrations, clinicians, nurses, cleaners, securities (activities unknown)	290 min (average: 240–350 min)	SARS-CoV-2 (Omicron)	Scrub suits (manufacturer unknown)	Top, trousers	Swabs (manufacturer unknown)	20 (10 per clothing area)	PCR	0.0%	N/A
Yao [17]	Unknown (500 and 1500 beds)	10	Administrations, clinicians, nurses, cleaners, securities (activities unknown)	290 min (average: 240–350 min)	SARS-CoV-2 (Omicron)	Coveralls (manufacturer unknown)	Sleeves, chest, cap	Swabs (manufacturer unknown)	30 (10 per clothing area)	PCR	10% (2/10 chest, 1/10 cap, 0/10 sleeves)	C_T values of chest samples: >35
Yung [51]	1 asymptomatic 6-month old infant with confirmed COVID-19 infection (very high viral load)	1	Nurse (carrying and feeding)	15 min	SARS-CoV-2 (original Wuhan strain)	Waterproof gown (manufacturer unknown)	Whole gown	Synthetic fibre flocked swabs with universal transport medium (Copan)	1	Real-time RT–PCR	0.0%	N/A

HCW, healthcare workers; AGPs, aerosol-generating procedures; RT–PCR, reverse transcriptase polymerase chain reaction; C_T, cycle threshold; N/A, not applicable; qPCR, quantitative PCR.

Table III
Study characteristics of studies belonging to category II: virus detection on clothing tested in a laboratory setting

Study	Clothing studied	Viruses studied (variant)	Experimental setup	Temperature	Relative humidity	Detection time-points	Detection method	Time virus remained detectable	Virus reduction over time
Córdoba-Lanús [20]	Gown (manufacturer unknown)	SARS-CoV-2 (human clinical nasopharyngeal sample; genomic RNA from heat-inactivated 2019-nCoV/USA-WA1/2020)	2 cm^2 pieces were inoculated with 10 μL of virus	Room temperature	Unknown	5 d, 10 d, 15 d, 20 d, 25 d, 30 d	RT—qPCR	5 d (for clinical sample and heat-inactivated virus strain)	Starting dose: 10^3 copies/μL. C_T values at day 5: 32.9 for clinical sample, 29.3 for heat-inactivated virus strain
Haddow [52]	Coverall (Tyvek) (DuPont)	SARS-CoV-2 (USA-WA1/2020)	6.3 mm^2 pieces were inoculated with 50 μL of virus	22 ± 2 °C	40—50%	4 h, 8 h, 24 h, 48 h, 72 h	Plaque assay	3 d	Challenge dose was 4.3 log_{10} pfu/mL. Titre at 72 h was 2.1 log_{10} pfu/mL
Harbourt [19]	Scrubs (35% cotton and 65% polyester) (Labforce)	SARS-CoV-2 (USA-WA1/2020)	6.3 mm^2 pieces were inoculated with 50 μL of virus	4 °C, 22 °C, 37 °C	40—50%	0 h, 4 h, 8 h, 24 h, 72 h, 96 h, 168 h, 336 h	Plaque assay	At 4 °C: 4 d; at 22 °C: 4 h; at 37 °C: 0 h	Starting titre: 4.5 log_{10} pfu. After 4 d and 4 h: 2.2 log_{10} pfu/mL
Kasloff [22]	Coverall (Tyvek) (DuPont)	SARS-CoV-2 (hCoV-19/Canada/ON-VIDO-01/2020)	1.4 cm^2 pieces were inoculated with 10 μL of virus suspension	20 °C	35—40%	1 h, 4 h, 1 d, 2 d, 3 d, 4 d, 7 d, 14 d, 21 d	$TCID_{50}$ assay	14 d	Reduced to very low levels compared to starting inoculum (7.88 log_{10} $TCID_{50}$/mL)
Kasloff [22]	T-shirt (cotton) (Fruit of the Loom)	SARS-CoV-2 (hCoV-19/Canada/ON-VIDO-01/2020)	1.4 cm^2 pieces were inoculated with 10 μL of virus suspension	20 °C	35—40%	1 h, 4 h, 1 d, 2 d, 3 d, 4 d, 7 d, 14 d, 21 d	$TCID_{50}$ assay	4 h	Reduced to very low levels compared to starting inoculum (7.88 log_{10} $TCID_{50}$/mL)
Paton [21]	Coverall (Tyvek) (manufacturer unknown)	SARS-CoV-2 (England 02/2020; EPI_ISL_407073)	1 cm^2 pieces were inoculated with 20 μL of virus suspension	21.5 °C	Average of 45%	0 h, 2.5 h, 24 h, 48 h, 72 h, 96 h, 144 h, 168 h, 336 h, 504 h	Plaque assay	7 d	Starting inoculum: 2×10^5 pfu/mL. Log_{10} reduction after 2.5 h of drying: 0.7
Paton [21]	Gown (plastic) (manufacturer unknown)	SARS-CoV-2 (England 02/2020; EPI_ISL_407073)	1 cm^2 pieces were inoculated with 20 μL of virus suspension	21.5 °C	Average of 45%	0 h, 2.5 h, 24 h, 48 h, 72 h, 96 h, 144 h, 168 h, 336 h, 504 h	Plaque assay	6 d	Starting inoculum: 2×10^5 pfu/mL. Log_{10} reduction after 2.5 h of drying: 0.18
Paton [21]	T-shirt (cotton) (Fruit of the Loom)	SARS-CoV-2 (England 02/2020; EPI_ISL_407073)	1 cm^2 pieces were inoculated with 20 μL of virus suspension	21.5 °C	Average of 45%	0 h, 2.5 h, 24 h, 48 h, 72 h, 96 h, 144 h, 168 h, 336 h, 504 h	Plaque assay	3 d	Starting inoculum: 2×10^5 pfu/mL. Log_{10} reduction after 2.5 h of drying: 1.34
Paton [21]	Sports shirt (polyester) (Activewear)	SARS-CoV-2 (England 02/2020; EPI_ISL_407073)	1 cm^2 pieces were inoculated with 20 μL of virus suspension	21.5 °C	Average of 45%	0 h, 2.5 h, 24 h, 48 h, 72 h, 96 h, 144 h, 168 h, 336 h, 504 h	Plaque assay	2.5 h	Starting inoculum: 2×10^5 pfu/mL. Log_{10} reduction after 2.5 h of drying: 3.66
Sakaguchi [18]	Gown (Tyvek) (DuPont)	Influenza A H1N1 (A/PR/8/34)	3 cm^2 pieces were inoculated with 500 μL of virus suspension	25.2 °C	55%	0 h, 1 h, 8 h, 24 h	$TCID_{50}$ assay and HA assay	8 h	$TCID_{50}$/mL: $10^{3.8}$ at 0 h, $10^{2.8}$ at 8 h. HA titre: 64 at 0 h, 32 at 1 h and 8 h.
Xue [23]	Apron (polyethylene) (BPI)	SARS-CoV-2 (CVR-GLA-1)	1 cm^2 pieces were inoculated with 10,000 μL of virus stock	Room temperature	Unknown	10 min	$TCID_{50}$ assay	10 min	Starting dose: 7.2×10^3 $TCID_{50}$ (3.9 log_{10} units). Virus recovered: 93.5%
Xue [23]	Scrubs (35% cotton and 65% polyester) (Fisher Scientific)	SARS-CoV-2	1 cm^2 pieces were inoculated with 10,000 μL of virus stock	Room temperature	Unknown	10 min	$TCID_{50}$ assay	10 min	Starting dose: 7.2×10^3 $TCID_{50}$ (3.9 log_{10} units). Virus recovered: 58.5%
Xue [23]	Scrubs (100% cotton) (UniMediForm)	SARS-CoV-2	1 cm^2 pieces were inoculated with 10,000 μL of virus stock	Room temperature	Unknown	10 min	$TCID_{50}$ assay	10 min	Starting dose: 7.2×10^3 $TCID_{50}$ (3.9 log_{10} units). Virus recovered: 100%

RT—qPCR, quantitative reverse transcriptase—polymerase chain reaction; C_T, cycle threshold; pfu, plaque-forming units; HA, haemagglutination assay.

Table IV
Study characteristics of studies belonging to category III: questionnaires about use of clothing and viral test results of HCWs

Study	No. of HCWs	Type of HCW	Clothing	% HCWs without protection	Viruses studied (+variant)	HCW testing	% Positive HCWs	*P*-value
Gaikwad [24]	51 coverall breaches (41 low-risk exposures, 10 high-risk exposures)	Nursing officers, doctors	Coverall with hood (manufacturer unknown)	100% (coverall breaches)	SARS-CoV-2	Low-risk exposure: allowed to continue working and self-monitoring. High-risk exposure: quarantined, tested on or after 7 d of exposure or if becoming symptomatic.	Overall: 3.9% (2/51). Low-risk exposures: 2.4% (1/41). High-risk exposures: 10.0% (1/10).	Unknown
Khalil [25]	190 (98 positive, 92 negative)	Physicians	Disposable gown (manufacturer unknown)	During usual care: 27 (21.1%) of the positive and 23 (22.5%) of the negative. During AGPs: 55 (21.8%) of the positive and 36 (17.6%) of the negative.	SARS-CoV-2	Positive group: positive RT–PCR test; negative group: no symptoms or negative test	N/A	During usual care: 0.825. During AGPs: 0.562.
Khalil [25]	190 (98 positive, 92 negative)	Physicians	Waterproof apron (manufacturer unknown)	During AGPs: 79 (65.5%) of the positive and 57 (48.5%) of the negative	SARS-CoV-2	Positive group: positive RT–PCR test; negative group: no symptoms or negative test	N/A	During AGPs: 0.060
Lai [26]	197 (89 infected, 108 non-infected)	Nurses, doctors, technicians, security and cleaning staff, financial staff	Protective suits (manufacturer unknown)	During operations: 69/89 (77.53%) of the infected and 31/108 (28.70%) of the uninfected. During AGPs: 8/17 (47.06%) of the infected and 5/26 (19.23%) of the uninfected.	SARS-CoV-2	Positive nucleic acid test or clinical diagnosis	N/A	During operations: <0.001. During AGPs: 0.052
Lai [26]	197 (89 infected, 108 non-infected)	Nurses, doctors, technicians, security and cleaning staff, financial staff	Gowns (manufacturer unknown)	During operations: 64/89 (71.91%) of the infected and 34/108 (31.48%) of the uninfected. During AGPs: 5/17 (29.41%) of the infected and 4/26 (15.38%) of the uninfected.	SARS-CoV-2	Positive nucleic acid test or clinical diagnosis	N/A	During operations: <0.001. During AGPs: 0.269
Seto [28]	254 (13 infected, 241 non-infected)	Nurses, doctors, healthcare assistants, domestic staff	Gown (manufacturer unknown)	100% of infected staff, 66% of non-infected staff (67.3% of total staff)	SARS-CoV-1	Sera were tested for antibodies using an indirect immunofluorescence test	5.1%	0.006

Shimbashi [27]	604	Office worker, doctor, nurse, nursing assistant, rehabilitation staff, radiologist, pharmacist, nutritionist, laboratory technician, social worker, psychologist, caregiver, cleaning staff	Gowns or aprons (manufacturers unknown)	Always wore gown/apron: 396 (65.6%), sometimes wore gown/apron: 135 (22.4%), never wore gown/apron: 73 (12.1%)	SARS-CoV-2	Serologic test: electrochemi-luminescence immunoassay (Elecsys Anti-SARS-CoV-2; Roche) or microneutralization assay (NIID)	Always wore gown/apron: 13.4% (53/396), sometimes wore gown/apron: 20.7% (28/135), never wore gown/apron: 17.8% (13/73)	Always wore gown/apron: 0.320, sometimes wore gown/apron: 0.612, never wore gown/apron: —
Teleman [29]	86 (36 cases, 50 controls)	Doctors, nurses, other HCWs	Gown (manufacturer unknown)	86.1% cases, 74.0% controls	SARS-CoV-1	Serology	41.9%	0.2
Yin [30]	257 (77 infected, 180 non-infected)	Unknown	Gown (manufacturer unknown)	27/77 infected HCWs wore gown (35%), 128/180 non-infected HCWs wore gown (71%); in total 40% of all HCWs did not wear gown	SARS-CoV-1	Unknown	30%	Unknown

HCWs, healthcare workers; AGPs, aerosol generating procedures; RT-PCR, reverse transcriptase PCR; N/A, not applicable.

clothing types. SARS-CoV-2 could be detected for longer periods of time on fluid-resistant materials compared to absorbent materials. This is consistent with findings from similar studies investigating SARS-CoV-2 infectivity on environmental surfaces [36–38]. A caveat of this category is that these were all laboratory studies, which means that the inoculation and sampling method might not reflect real-life inoculation and transmission mechanics. The inoculation titre used in the study of Kasloff *et al.* (7.88 $\log_{10}$ $TCID_{50}$/mL) [22], for example, is not reflective of an average clinically relevant titre [39]. Likewise, the study of Xue *et al.* inoculated the clothing pieces with 10 mL of virus stock [23], which is an unrealistic amount of fluid to be transmitted from a patient to an HCW. Ideally, the inoculation should mimic a natural inoculation, such as a sneeze or cough. One study did use micro-droplets from clinical nasopharyngeal samples; however, RT–qPCR was used instead of a culture-based method to detect the virus [20]. Thus, infectivity of respiratory viruses on clothing in a real healthcare setting still remains to be studied.

Most studies from category III did not find a significant effect between HCWs not wearing protective clothing and those same HCWs becoming infected. The percentage of infected HCWs who reported not wearing protective clothing was higher for general operations than for aerosol-generating procedures, which suggests that HCWs are more inclined to protect themselves in high-risk situations. This category is prone to recall bias, as studies involving questionnaires rely on the memory of its participants. Furthermore, the provided evidence was mostly circumstantial, since the exact cause of the HCWs becoming infected was not determined. To confirm with certainty that the patients which the HCWs were taking care of were the source of infection, whole genome sequence typing is needed [40].

In category IV, the included studies were quite heterogeneous, which hinders the assessment of this category as a whole. Both studies involving real respiratory viruses found that the alternative clothing, namely cotton gowns or no gowns, provided the same level of protection against infection as a standard gown. For the cotton gowns, however, the HCW infection rate was assessed, even though the HCWs wore other PPE such as an N95 mask, gloves, and a face shield. As infection rates of patients and possible transmission between patients were not assessed in this study, it remains unclear whether cotton gowns would provide sufficient protection for patients. The other two studies were both randomized controlled trials that made use of fluorescent substance, which might not accurately represent infectious virus and airborne particle dynamics. One of these studies found that short-sleeved gowns were as effective as long-sleeved gowns in protecting HCWs from contamination, provided that hand and arm hygiene was practised. In category I, 12% of all sleeve samples showed contamination. Substituting long-sleeved gowns by short-sleeved gowns along with hand and arm hygiene might be sufficient to eliminate this 12% of contamination. A study by Meda *et al.*, investigating bacterial contamination in a COVID-19 critical care unit, even found that this change led to lower bacterial contamination rates, as the long sleeves prevented HCWs from performing proper hand hygiene [41].

The current review found a variety of studies investigating different aspects of gown use during the care of patients with respiratory viruses. However, the transmission potential of such viruses from HCW clothing remains unanswered. Based on

Table V
Study characteristics of studies belonging to category IV: different clothing types tested in a real or simulated healthcare setting

Study	Patient population	No. of HCWs	Type of HCW	Experimental setup	Clothing	Viruses studied (+variant)	No. of infections/ contaminations
Dix [31]	3 simulated patients	9 participants	Members of a physical intervention team	UV material was placed or sprayed on patient, staff in three clothing sets performed intervention[a]; afterwards the amount and location of transferred UV material was assessed	Disposable coveralls (A), disposable scrubs (B), scrubs (C) (manufacturers not mentioned)	UV fluorescent substance (no virus)	Coveralls (long-sleeved) performed much better at preventing transfer of contaminant (including after cleansing using wipes) than short sleeves
Farhat [33]	COVID-19 patients (number unknown, 1180 shifts in total)	13 each day	6 nurses, 3 assistant nurses, 2 residents, 1 fellow, 1 staff	HCWs wore cotton surgical gowns instead of air-impermeable plastic gowns with head-to-toe cover during patient care, and were evaluated for clinical signs after 3 months	Cotton surgical gowns (produced in the local tailoring workshop of the hospital)	SARS-CoV-2	No symptoms or absence due to illness observed among HCWs
Pelke [34]	313 infants	Unknown	Nurses, ward clerks, residents, physicians, other hospital staff, families, visitors	Alternate 2-month gowning and no-gowning cycles were established, infection rates of both were determined by surveillance cultures (3 cultures per week for each infant)	Hospital-laundered scrub dresses/suits, gowns (A); hospital-issued pantsuits washed at home, street clothes (B) (manufacturers not mentioned)	RSV	Gowning: 0.08 per 100 patient days, no gowning: 0.06 per 100 patient days
Vincent [32]	17 simulated patients	67 participants	Nurses, physiotherapists, doctors	Two simulated activities[b] were performed once in long-sleeved gown and once in short-sleeved gown. Afterwards contamination on sleeves and forearms (after washing) was evaluated.	Long-sleeved gown with plastic apron (A), short-sleeved gown with plastic apron (B) (manufacturers not mentioned)	UV fluorescent substance (no virus)	Long-sleeves: 30/67 and 15/17, short-sleeves: 0/67 and 1/17. After final doffing: 7/67 in long-sleeved group showed contamination, 18/67 in short-sleeved group.

HCWs, healthcare workers; UV, ultraviolet; RSV, respiratory syncytial virus.
[a] Simulated physical intervention by a predetermined choreography. Spitting of oral fluid was simulated using UV fluorescent material consistent with training aids for infection control.
[b] Simulated activities: (1) oral endo-tracheal intubation of a simulated patient (a mannequin), with respiratory failure, secondary to COVID-19 pneumonia, (2) turning a simulated patient (an actor) from the supine position (lying on back) into the prone position (lying on front).

category I, it may be concluded that respiratory viruses have the potential to adhere to (protective) clothing of HCW; based on category II, it may be assumed that these viruses sometimes are viable. While category III and IV did not provide much solid evidence, category IV does suggest that short sleeves could suffice as an alternative to long-sleeved gowns. Introducing an alternative option or completely discontinuing the use of gowns would be favourable in terms of sustainability. The carbon footprint of gowns is substantial, especially due to the production process and generated waste [6,42]. The use of gowns can also generate discomfort for HCWs [43], and can lead to negative effects for patients, for instance due to slower reaction time [44]. To discontinue the use of gowns altogether, evidence would be needed that respiratory viruses cannot be transmitted from a standard uniform. Pelke *et al.* were the only group that compared the use of gowns with no gowns in a real patient setting [34]. That study dates back to 1994 and only focused on the patient population, not on HCWs. We believe that other similar trials are needed to adequately evaluate the effect of gowning on the patient and HCW population. However, we acknowledge that such trials are methodologically complex and associated with multiple ethical considerations, which is likely the reason only one was found in our search and included in this review. This could be solved by well-controlled laboratory experiments mimicking real-life healthcare settings and patient care situations, although in modern medicine this is considered low-quality evidence compared to randomized controlled trials [45].

The main strength of this review is the extensive literature search that was performed. This resulted in a complete overview of the existing evidence regarding the use of gowns during care of patients with respiratory viruses, and made it possible to identify the knowledge gaps.

This review had some limitations. The included studies showed quite a high heterogeneity, even within the categories, and observed various viruses and clothing types. This would at times limit the number of studies that could be combined in order to draw conclusions from each category. Additionally, after extracting the data from each study and contacting the authors, multiple missing characteristics remained — for instance, some clothing areas in category I and clothing materials in category II. This too hampered the evaluation of these categories, as for these aspects certain studies had to be excluded. Finally, publication bias may be present. To mitigate this, we performed a broad search strategy aiming to include all available evidence. Selection bias was addressed by having two authors independently perform the selection process.

In conclusion, the results showed that viral RNA can be found on clothing after caring for patients with respiratory viruses, and respiratory viruses can remain viable on clothing when artificially deposited. On the other hand, there is limited evidence, primarily from survey studies, that HCWs became infected while not wearing protective clothing. Other studies suggest that there might be safe alternative options to long-sleeved gowns, such as short-sleeved gowns in combination with hand and arm hygiene. Importantly, it remains unclear whether viable viruses can be transmitted from standard uniforms to patients. Although there is some indication of a protective effect of long-sleeved gowns, the current level of evidence is insufficient to draw firm conclusions.

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Author contributions

All authors were involved in the design of this review. L.O. and A.V. performed the title/abstract and full text screenings and extracted data from the included studies. L.O. performed the data analysis. L.O. and A.V. drafted the initial manuscript. All authors revised and approved the final manuscript.

Conflict of interest statement

None declared.

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Ethical approval

Not required.

Appendix A. Supplementary data

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