Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Journal of Hospital Infection 108 (2021) 120–134

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Review

Seroprevalence of SARS-CoV-2 antibodies and associated factors in healthcare workers: a systematic review and meta-analysis

P. Galanis [a,*], I. Vraka [b], D. Fragkou [a], A. Bilali [c], D. Kaitelidou [a]

[a] Faculty of Nursing, Centre for Health Services Management and Evaluation, National and Kapodistrian University of Athens, Athens, Greece
[b] Department of Radiology, P & A Kyriakou Children's Hospital, Athens, Greece
[c] Hospital Waste Management Unit, P & A Kyriakou Children's Hospital, Athens, Greece

ARTICLE INFO

Article history:
Received 9 October 2020
Accepted 10 November 2020
Available online 16 November 2020

Keywords:
SARS-CoV-2
COVID-19
Seroprevalence
Antibodies
Healthcare workers

SUMMARY

Background: Healthcare workers (HCWs) represent a high-risk population for infection with severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2).
Aim: To determine the seroprevalence of SARS-CoV-2 antibodies among HCWs, and identify the factors associated with this seroprevalence.
Methods: The Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines were applied for this systematic review and meta-analysis. Databases including PubMed/MEDLINE and preprint services (medRχiv and bioRχiv) were searched from inception to 24th August 2020.
Findings: Forty-nine studies including 127,480 HCWs met the inclusion criteria. The estimated overall seroprevalence of SARS-CoV-2 antibodies among HCWs was 8.7% (95% confidence interval 6.7–10.9%). Seroprevalence was higher in studies conducted in North America (12.7%) compared with those conducted in Europe (8.5%), Africa (8.2) and Asia (4%). Meta-regression showed that increased sensitivity of antibody tests was associated with increased seroprevalence. The following factors were associated with seropositivity: male gender; Black, Asian and Hispanic HCWs; work in a coronavirus disease 2019 (COVID-19) unit; patient-related work; front-line HCWs; healthcare assistants; shortage of personal protective equipment; self-reported belief of previous SARS-CoV-2 infection; previous positive polymerase chain reaction test; and household contact with suspected or confirmed cases of COVID-19.
Conclusion: The seroprevalence of SARS-CoV-2 antibodies among HCWs is high. Excellent adherence to infection prevention and control measures; sufficient and adequate personal protective equipment; and early recognition, identification and isolation of HCWs infected with SARS-CoV-2 are imperative to decrease the risk of SARS-CoV-2 infection.

Introduction

Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) and coronavirus disease 2019 (COVID-19) emerged from Wuhan, Hubei Province, China in December 2019, and the

* Corresponding author. Address: Faculty of Nursing, Centre for Health Services Management and Evaluation, National and Kapodistrian University of Athens, 123 Papadiamantopoulou Street, GR-11527 Athens, Greece.
E-mail address: pegalan@nurs.uoa.gr (P. Galanis).

https://doi.org/10.1016/j.jhin.2020.11.008
0195-6701/

World Health Organization (WHO) declared a pandemic situation on 11th March 2020 [1]. As of 2nd October 2020, WHO reported 34,079,542 cases and 1,015,963 deaths globally due to COVID-19 [2].

Healthcare workers (HCWs) are a high-risk group for infection. A recent meta-analysis with 11 studies found that the proportion of HCWs who were SARS-CoV-2 positive among all patients with COVID-19 was 10.1%, but severity and mortality among HCWs were lower than among all patients with COVID-19 [3]. This proportion varied substantially between countries: China, 4.2%; Italy, 9%; and USA, 17.8% [3]. The lower proportion in China is probably due to immediate implementation of strong public health interventions, such as lockdown measures, home isolation, quarantine measures, wearing masks and social (physical) distancing [4].

SARS-CoV-2 and COVID-19 have significant diagnostic issues, and serological tests aim to identify previous SARS-CoV-2 infection by detecting the presence of SARS-CoV-2 antibodies. It is known that SARS-CoV-2 antibody tests are accurate to detect previous SARS-CoV-2 infection if performed >14 days after the onset of symptoms, but they have very low sensitivity in the first week after symptom onset [5]. Also, rapid diagnostic tests for SARS-CoV-2 antibodies have low pooled sensitivity (64.8) and high pooled specificity (98%), but these data suffer from low power and other significant limitations [6].

Knowledge of the seroprevalence of SARS-CoV-2 antibodies among HCWs is important to understand the spread of COVID-19 among healthcare facilities, and to assess the success of public health interventions. To the authors' knowledge, the overall seroprevalence of SARS-CoV-2 antibodies among HCWs and the associated factors are unknown. Thus, the primary objective of this systematic review and meta-analysis was to determine the seroprevalence of SARS-CoV-2 antibodies among HCWs, and the secondary objective was to identify the factors associated with this seroprevalence.

Methods

Data sources and strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were applied in this systematic review and meta-analysis [7]. The PRISMA checklist is presented in Table S1 (see online supplementary material). PubMed/MEDLINE and preprint services (medRχiv and bioRχiv) were searched from inception to 24th August 2020. In addition, reference lists of all relevant articles were searched, and duplicates were removed. The following search strategy was used: ('sars-cov-2 antibodies' OR 'COVID-19 antibodies' OR 'sars-cov-2' OR 'COVID-19' OR antibodies) AND ('health care personnel' OR 'healthcare personnel' OR 'health-care personnel' OR 'health care workers' OR 'health-care workers' OR 'healthcare workers' OR 'healthcare staff' OR 'health care staff' OR 'health-care staff' OR 'medical staff').

Selection and eligibility criteria

Two authors undertook study selection independently, and a third (senior) author resolved any disagreements. All studies written in English (except case reports) that reported the seroprevalence of SARS-CoV-2 antibodies among HCWs and associated factors were included. In addition, studies reporting any serological test (e.g. enzyme-linked immunosorbent assay, chemiluminescence immunoassay) used to detect SARS-CoV-2 antibodies (IgA, IgG and IgM) in all HCWs were included. Finally, studies performed under screening conditions where HCWs were not selected for participation based on previous exposure to SARS-CoV-2 or symptoms were also included.

Data extraction and quality assessment

Data collected included authors, location, dates of data collection, sample size, setting, study design, antibody tests, sensitivity and specificity of antibody tests, number of HCWs with SARS-CoV-2 antibodies, factors associated with seroprevalence of SARS-CoV-2 antibodies, and level of analysis (univariate or multi-variate).

The quality of studies was assessed using the Joanna Briggs Institute critical appraisal tools, where a nine-point scale is used for prevalence studies, an eight-point scale is used for cross-sectional studies and an 11-point scale is used for cohort studies [8]. In prevalence studies, a score of 8–9 indicates good quality, a score of 5–7 indicates moderate quality and a score ≤4 indicates poor quality. In cross-sectional studies, a score of 7–8 indicates good quality, a score of 4–6 indicates moderate quality and a score ≤3 indicates poor quality. In cohort studies, a score of 9–11 indicates good quality, a score of 5–8 indicates moderate quality and a score ≤4 indicates poor quality.

Statistical analysis

For each study, the total number of HCWs and the number of HCWs who were positive for SARS-CoV-2 antibodies were extracted. Seroprevalence and 95% confidence intervals (CI) were calculated for each included study. Seroprevalence was transformed with the Freeman–Tukey double arcsine method before pooling [9]. Between-studies heterogeneity was assessed using Hedges Q statistic and I^2 statistic. Statistical significance for Hedges Q statistic is set at $P<0.1$, while I^2 values >75% indicate high heterogeneity [10]. A random effects model was applied to estimate pooled seroprevalence as heterogeneity between results was very high [10,11]. Study quality, sample size, sensitivity and specificity of antibody tests, publication type (journal or preprint service) and the continent where studies were conducted were considered as prespecified sources of heterogeneity, and explored using subgroup analysis and meta-regression analysis. In addition, leave-one-out sensitivity analysis was performed by removing one study at a time to determine the influence of each study on overall prevalence. A funnel plot and Egger's test were used to assess publication bias. $P<0.05$ for Egger's test indicates publication bias [12]. Meta-analysis was not performed for factors associated with the seroprevalence of SARS-CoV-2 antibodies as the data were very scarce. Statistical analysis was performed using OpenMeta[Analyst] [13].

Results

Identification and selection of studies

A flowchart of the literature search is summarized in PRISMA format (Figure 1). Initially, 3632 potential records were

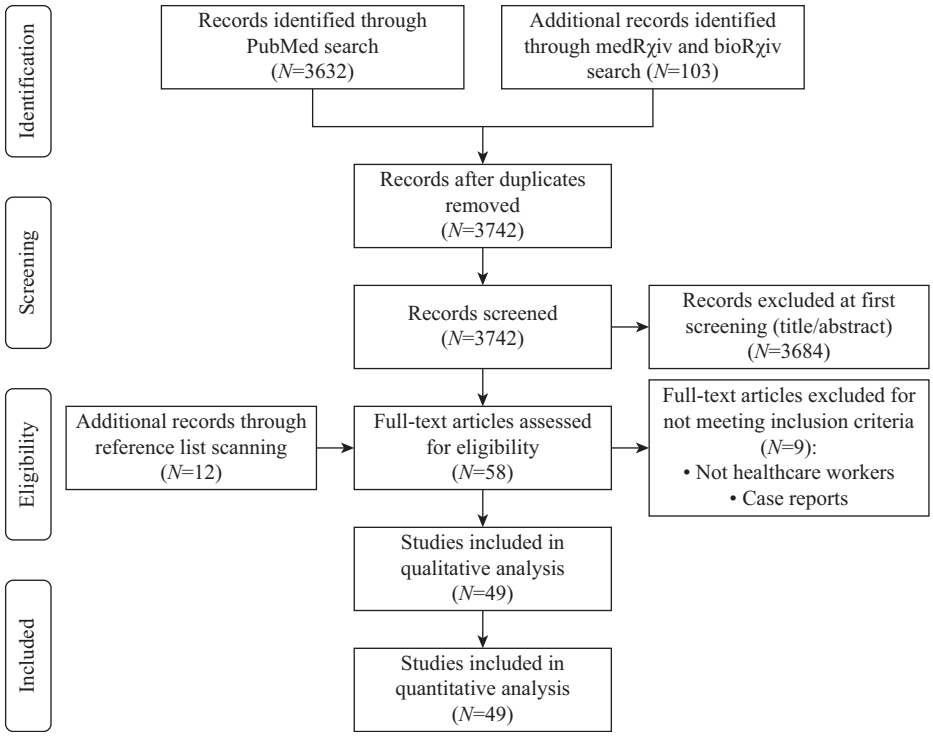

Figure 1. Flowchart of the literature search according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.

identified through PubMed and 103 records were identified through preprint services for health sciences (i.e. medRχiv and bioRχiv) after removal of duplicates. After screening the titles and abstracts, 3684 records were removed. Twelve additional records were identified and included after searching the reference lists. Finally, 49 studies that met the inclusion criteria were included in this meta-analysis.

Characteristics of the studies

The main characteristics of the 49 studies included in this systematic review and meta-analysis are shown in Table I. In total, 127,480 HCWs were included. Forty-nine studies [14—62] reported data regarding the seroprevalence of SARS-CoV-2 antibodies among HCWs, and 27 studies [14,15,18,19,21—25,27—32,34—37,39,44,47,52,54,58,60,61] investigated factors for SARS-CoV-2 antibody positivity.

The majority of studies were conducted in Europe (*N*=31), followed by North America (*N*=9), Asia (*N*=6) and Africa (*N*=3). In particular, nine studies were conducted in the USA [14,15,24,26,27,29,32,34,40], eight studies in Italy [23,28,30,36,44,45,56,57], seven studies in the UK [16,17,20,25,33,59,61], five studies in Germany [21,35,42,43,46], four studies in Spain [31,38,49,52], three studies in Japan [53,58,62], three studies in Belgium [18,19,22] and three studies in China [47,48,51]. Twenty-nine studies did not report the response rate [15—17,20,24,26—30,32—34,38,40—43,45,47,48,50,51,55—59,62], nine studies did not report the ages of HCWs [17,18,21,23,32,33,36,41,48], eight studies did not report the sex distribution of HCWs [16,18,21,25,32,33,41,48] and five studies did not report the dates of data collection [17,36,43,48,56]. The percentage of females ranged from 35% [62] to 88.5% [51], and was higher compared with the percentage of males in 41 studies; in three studies, the percentage of males was higher than the percentage of females. The mean age of HCWs ranged from 31.2 [51] years to 47.9 years [57], while sample size ranged from 25 [40] to 40,329 HCWs [14]. Regarding study design, 26 cross-sectional studies [14,15,18,19,21,23—25,27—32,34—37,39,44,47,52,54,58,60,61], 20 prevalence studies [17,26,33,38,40—43,45,46,48—51,53,55—57,59,62] and three cohort studies [16,20,22] were included in this review. All studies except one [31] used a convenience sample, and the response rate ranged from 47.7% [19] to 100% [36,60]. Forty-two studies were conducted in hospitals [15—24,26,27,29—48,50—62], four studies in primary care facilities and hospitals [14,25,28,49], two studies in primary care facilities [35,62] and one study in a cancer centre [59]. Thirty-five studies were published in journals [14—48], and 14 studies were published in preprint services [49—62].

Validity assessment (sensitivity and specificity) for antibody tests used in the included studies according to the manufacturers' data are presented in Table S2 (see online supplementary material). Sensitivity ranged from 50% to 100%, and specificity ranged from 80.5% to 100%.

Quality assessment

Quality assessments of prevalence studies, cross-sectional studies and cohort studies are shown in Tables S3, S4 and S5, respectively (see online supplementary material). Quality was moderate in 37 studies, good in 10 studies and poor in two studies. Regarding prevalence studies, 16 were at moderate risk of bias, three were at low risk and one was at high risk. Moreover, 20 cross-sectional studies were at moderate risk of

Table I
Main characteristics of studies included in the systematic review and meta-analysis

Reference	City or state/country	Females (%)	Age (years), mean (SD)	Sample size (*N*)	Study design	Sampling method	Response rate (%)	Dates of data collection	Setting	Publication
Moscola *et al.*, 2020 [14]	New York/USA	73.7	42.7 (17.1)	40,329	Cross-sectional	Convenience sampling	65.1	20 April—23 June	Primary care facilities and hospitals	Journal
Jeremias *et al.*, 2020 [15]	New York/USA	70.2	42.8 (13.8)	1699	Cross-sectional	Convenience sampling	NR	1 March—30 April	Hospitals	Journal
Houlihan *et al.*, 2020 [16]	London/UK	NR	35.8 (11.2)	181	Cohort	Convenience sampling	NR	26 March—8 April	Hospitals	Journal
Poulikakos *et al.*, 2020 [17]	North West England/ UK	73	NR	281	Prevalence	Convenience sampling	NR	NR	Hospitals	Journal
Steensels *et al.*, 2020 [18]	Genk/Belgium	NR	NR	3056	Cross-sectional	Convenience sampling	74	22—30 April	Hospitals	Journal
Blairon *et al.*, 2020 [19]	Brussels/Belgium	72.4	43.9 (1.7)[a] 47.4 (2.1)[b]	1485	Cross-sectional	Convenience sampling	47.7	25 May—19 June	Hospitals	Journal
Pallett *et al.*, 2020 [20]	London/UK	72.7	39.1 (12.1)	6440	Cohort	Convenience sampling	NR	8 April—12 June	Hospitals	Journal
Korth *et al.*, 2020 [21]	Essen/Germany	NR	NR	316	Cross-sectional	Convenience sampling	65	25 March—21 April	Hospitals	Journal
Martin *et al.*, 2020 [22]	Brussels/Belgium	73	37 (11.3)	326	Cohort	Convenience sampling	87.3	15 April—18 May	Hospitals	Journal
Amendola *et al.*, 2020 [23]	Milan/Italy	83.7	NR	547	Cross-sectional	Convenience sampling	89.4	15 April	Hospitals	Journal
Self *et al.*, 2020 [24]	Washington, Oregon, California, Minnesota, Tennessee, Ohio, North Carolina, New York, Massachusetts, Utah, Colorado, Maryland/USA	65.6	38.5 (12.6)	3248	Cross-sectional	Convenience sampling	NR	3 April—19 May	Hospitals	Journal
Grant *et al.*, 2020 [25]	London/UK	NR	40.3 (11.1)	2004	Cross-sectional	Convenience sampling	54.2	15 May—5 June	Primary care facilities and hospitals	Journal
Mughal *et al.*, 2020 [26]	New Jersey/USA	75	38.5 (15.4)	121	Prevalence	Convenience sampling	NR	1 March—30 April	Hospitals	Journal
Hunter *et al.*, 2020 [27]	Indiana/USA	70.1	43 (NR)	690	Cross-sectional	Convenience sampling	NR	29 April—8 May	Hospitals	Journal
Plebani *et al.*, 2020 [28]	Veneto Region/Italy	71.6	43.2 (11.6)	8285	Cross-sectional	Convenience sampling	NR	22 February—29 May	Primary care facilities and hospitals	Journal
Mansour *et al.*, 2020 [29]	New York/USA	46	38.4 (10.8)	285	Cross-sectional	Convenience sampling	NR	24 March—4 April	Hospitals	Journal

(*continued on next page*)

Table I (*continued*)

Reference	City or state/country	Females (%)	Age (years), mean (SD)	Sample size (*N*)	Study design	Sampling method	Response rate (%)	Dates of data collection	Setting	Publication
Sotgiu *et al.*, 2020 [30]	Milan/Italy	65.3	44.6 (14.2)	202	Cross-sectional	Convenience sampling	NR	2–16 April	Hospitals	Journal
Garcia-Basteiro *et al.*, 2020 [31]	Barcelona/Spain	72.1	42.1 (11.6)	578	Cross-sectional	Random sampling	74.3	9 March	Hospitals	Journal
Sydney *et al.*, 2020 [32]	New York/USA	NR	NR	1700	Cross-sectional	Convenience sampling	NR	28 April–4 May	Hospitals	Journal
Khalil *et al.*, 2020 [33]	London/UK	NR	NR	190	Prevalence	Convenience sampling	NR	15–28 May	Hospitals	Journal
Stubblefield *et al.*, 2020 [34]	Tennessee/USA	65.5	33.7 (8.7)	249	Cross-sectional	Convenience sampling	NR	3–13 April	Hospitals	Journal
Lackermair *et al.*, 2020 [35]	Bavaria/Germany	83	37.9 (4)	151	Cross-sectional	Convenience sampling	63.7	2–6 April	Primary care facilities	Journal
Paderno *et al.*, 2020 [36]	Brescia/Italy	65.5	41 (NR)	58	Cross-sectional	Convenience sampling	100	NR	Hospitals	Journal
Kassem *et al.*, 2020 [37]	Cairo/Egypt	59.5	32.5 (5.2)	74	Cross-sectional	Convenience sampling	58.7	1–14 June	Hospitals	Journal
Olalla *et al.*, 2020 [38]	Marbella/Spain	80	41.5 (8.9)	498	Prevalence	Convenience sampling	NR	15–25 April	Hospitals	Journal
Iversen *et al.*, 2020 [39]	Capital Region of Denmark/Denmark	78.9	44.4 (12.6)	28,792	Cross-sectional	Convenience sampling	96.3	17–22 April	Hospitals	Journal
Hains *et al.*, 2020 [40]	Indiana/USA	88	41.2 (9.2)	25	Prevalence	Convenience sampling	NR	25 March–11 April	Hospitals	Journal
Solodky *et al.*, 2020 [41]	Lyon/France	NR	NR	244	Prevalence	Convenience sampling	NR	1 March–16 April	Hospitals	Journal
Behrens *et al.*, 2020 [42]	Hannover, Germany	65	36.5 (11.3)	217	Prevalence	Convenience sampling	NR	23 March–17 April	Hospitals	Journal
Brandstetter *et al.*, 2020 [43]	Regensburg/Germany	85.1	18–35 years, 35.8%; 36–50 years, 35.8%; 51–65 years, 28.4%	201	Prevalence	Convenience sampling	NR	NR	Hospitals	Journal
Fusco *et al.*, 2020 [44]	Naples/Italy	49	42.1 (14.6)	115	Cross-sectional	Convenience sampling	95.8	23 March–2 April	Hospitals	Journal
Lahner *et al.*, 2020 [45]	Rome/Italy	63.8	45.2 (11.1)	2115	Prevalence	Convenience sampling	NR	18 March–27 April	Hospitals	Journal
Schmidt *et al.*, 2020 [46]	Hessisch Oldendorf/ Germany	80	18–29 years, 14.3%; 30–49 years,	406	Prevalence	Convenience sampling	77.3	20–30 April	Hospitals	Journal

			40%; 50–64 years, 44.2%; >64 years, 1.5%							
Xu *et al.*, 2020 [47]	Hubei Province, Chongqing, Guangzhou, Guangdong/China	75.2	37.1 (13.3)	4384	Cross-sectional	Convenience sampling	NR	9 March–10 April	Hospitals	Journal
Zhao *et al.*, 2020 [48]	Beijing, Zhejiang province/China	NR	NR	276	Prevalence	Convenience sampling	NR	NR	Hospitals	Journal
Fernández-Rivas *et al.*, 2020 [49]	Barcelona/Spain	76	43.8 (12.4)	7563	Prevalence	Convenience sampling	81.2	4–22 May	Primary care facilities and hospitals	Preprint service
Kammon *et al.*, 2020 [50]	Alzintan/Libya	53	>40 years, 37.4%	77	Prevalence	Convenience sampling	NR	2 April–18 May	Hospitals	Preprint service
Xiong *et al.*, 2020 [51]	Wuhan/China	88.5	31.2 (4.7)	797	Prevalence	Convenience sampling	NR	12 February–17 March	Hospitals	Preprint service
Galán *et al.*, 2020 [52]	Madrid/Spain	73.9	43.8 (11.1)	2590	Cross-sectional	Convenience sampling	90.5	14–27 April	Hospitals	Preprint service
Nakamura *et al.*, 2020 [53]	Iwate/Japan	73.6	40 (11)	1000	Prevalence	Convenience sampling	76.8	18–29 May	Hospitals	Preprint service
Psichogiou *et al.*, 2020 [54]	Athens/Greece	69.7	46.4 (10.3)	1495	Cross-sectional	Convenience sampling	77	13 April–15 May	Hospitals	Preprint service
Chibwana *et al.*, 2020 [55]	Blantyre/Malawi	53	31.4 (7.3)	500	Prevalence	Convenience sampling	NR	22 May–19 June	Hospitals	Preprint service
Tosato *et al.*, 2020 [56]	Padova/Italy	88	47 (10)	133	Prevalence	Convenience sampling	NR	NR	Hospitals	Preprint service
Paradiso *et al.*, 2020 [57]	Bari/Italy	60.6	47.9 (8.6)	606	Prevalence	Convenience sampling	NR	26 March–17 April	Hospitals	Preprint service
Fujita *et al.*, 2020 [58]	Kyoto/Japan	64.1	20–29 years, 32.6%; 30–39 years, 31.5%; 40–49 years, 22.8%; >49 years, 13%	92	Cross-sectional	Convenience sampling	NR	10–20 April	Hospitals	Preprint service
Sikora *et al.*, 2020 [59]	Reading, Newport, Liverpool, Bedlington/UK	50.3	43 (NR)	161	Prevalence	Convenience sampling	NR	14–24 April	Cancer centers	Preprint service
Rudberg *et al.*, 2020 [60]	Stockholm/Sweden	85	44 (12)	410	Cross-sectional	Convenience sampling	100	14 April–8 May	Hospitals	Preprint service

(*continued on next page*)

Table I (*continued*)

Reference	City or state/country	Females (%)	Age (years), mean (SD)	Sample size (*N*)	Study design	Sampling method	Response rate (%)	Dates of data collection	Setting	Publication
Shields *et al.*, 2020 [61]	Birmingham/UK	75.2	40.9 (15.6)	516	Cross-sectional	Convenience sampling	93.1	25 April	Hospitals	Preprint service
Takita *et al.*, 2020 [62]	Tokyo/Japan	35	20–29 years, 0%; 30–39 years, 9%; 40–49 years, 36%; 50–59 years, 16%; 60–69, 31%; 70–80 years, 7%	55	Prevalence	Convenience sampling	NR	21–28 April	Primary care facilities	Preprint service

NR, not reported; SD, standard deviation.
[a] For females.
[b] For males.

bias, five were at low risk and one was at high risk. Two cohort studies were at low risk of bias and one was at moderate risk.

Meta-analysis of the seroprevalence

A random effects model was applied to estimate pooled prevalence as heterogeneity between results was very high (I^2=99.34, *P*-value for Hedges *Q* statistic <0.001). The estimated overall seroprevalence of SARS-CoV-2 antibodies among HCWs was 8.7% (95% CI 6.7–10.9%) (Figure 2). Seroprevalence among studies ranged from 0% to 45.3%.

Subgroup and meta-regression analysis

According to subgroup analysis, seroprevalence of SARS-CoV-2 antibodies was higher for studies of poor quality (11.6%, 95% CI 0.7–32.7%) compared with studies of moderate quality (8.8%, 95% CI 6.0–12%) and good quality (7.9%, 95% CI 4.1–12.8%). Moreover, seroprevalence was higher for studies that had been published in journals (9%, 95% CI 6.7–11.6%) compared with preprint services (7.7%, 95% CI 3.4–13.4%). Seroprevalence was higher in studies conducted in North America (12.7%, 95% CI 8.6–17.5%) compared with those conducted in Europe (8.5%, 95% CI 5.8–11.6%), Africa (8.2%, 95% CI 0.8–22.3%) and Asia (4%, 95% CI 1.8–7.1%). Meta-regression showed that increased sensitivity of antibody tests was associated with increased seroprevalence (coefficient = 0.004, 95% CI 0.0001–0.009; *P*=0.038). Moreover, seroprevalence was independent of sample size (*P*=0.65) and specificity (*P*=0.20).

Sensitivity analysis

Leave-one-out sensitivity analysis showed that no single study had a disproportionate effect on overall seroprevalence, which varied between 8.2% (95% CI 6.2–10.3%) with Hoolihan *et al.* [16] excluded and 9.0% (95% CI 6.9–11.2%) with Nakamura *et al.* [53] excluded (Figure S1, see online supplementary material).

Publication bias

Egger's test (*P*=0.0001) and the asymmetric shape of the funnel plot (Figure S2, see online supplementary material) implied potential publication bias.

Factors associated with SARS-CoV-2 antibody positivity

Twenty-seven studies [14,15,18,19,21–25,27–32,34–37,39,44,47,52,54,58,60,61] investigated factors associated with SARS-CoV-2 antibody positivity, and 13 studies found associations [14,18,23–25,28,30,32,34,36,39,47,60] (Table II). Twenty-four studies [15,19,21–25,27–32,34–37,44,47,52,54,58,60,61] used univariate analysis, and three studies [14,18,39] used multivariate regression analysis.

Three studies [24,30,39] found that SARS-CoV-2 antibodies were more frequently detectable in males, with odds ratios (OR) ranging from 1.39 to 3.21. Results regarding age were controversial as SARS-CoV-2 antibody positivity was associated with HCWs aged <30 years (OR=1.40, 95% CI 1.22–1.60) [39], HCWs aged ≥40 years (OR=1.36, 95% CI 1.09–1.60) [28] and

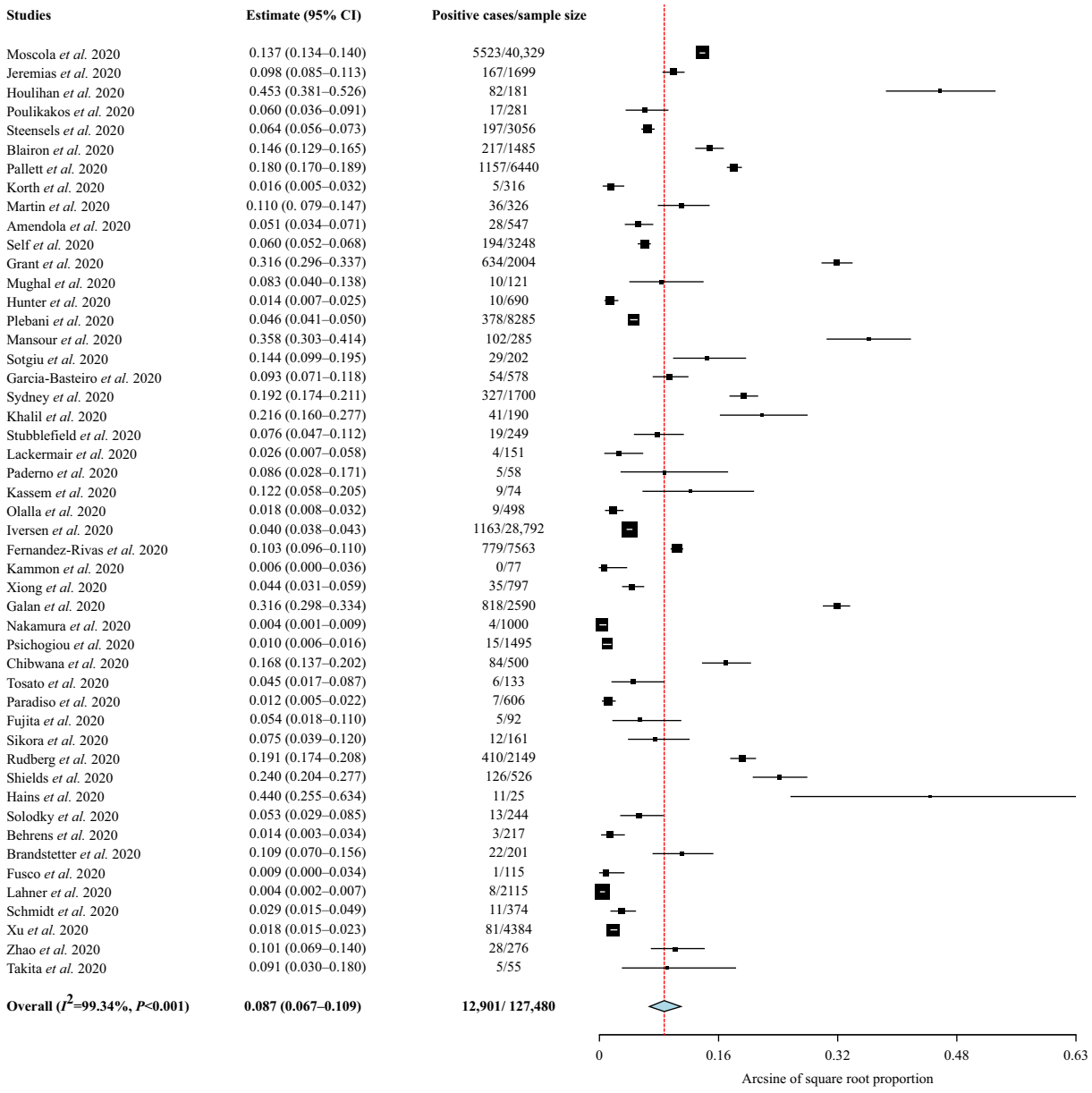

Figure 2. Forest plot of the seroprevalence of severe acute respiratory syndrome coronavirus-2 antibodies with corresponding 95% confidence intervals. The size of the black boxes is positively proportional to the weight assigned to studies, and horizontal lines represent the 95% confidence intervals according to random effects analysis.

HCWs aged ≥65 years (P<0.001) [47]. Significantly higher percentages of SARS-CoV-2 antibodies were found among African American HCWs (P<0.05) [32] and Black, Asian and Hispanic HCWs compared with White HCWs (OR=2.30, 95% CI 1.71–3.10; P<0.001) [24].

Three studies [25,39,60] found a significantly higher probability of a positive SARS-CoV-2 antibody test in HCWs working in a COVID-19 unit, with ORs ranging from 1.4 to 1.67. Similar results were found for HCWs with patient-related work (OR 1.22–2.9) [25,39,60] and front-line HCWs (OR=1.38, 95% CI 1.22–1.56) [39]. Moreover, Self *et al.* [24] found that HCWs working in a surgery department (OR=6.47, 95% CI 2.37–17.63) and a paediatric intensive care unit (OR=3.77, 95% CI 1.44–9.89; P=0.007) had a significantly higher percentage of SARS-CoV-2 antibodies. Two studies [28,60] found that SARS-CoV-2 antibody positivity was higher among healthcare assistants (OR=1.39, 95% CI 1.05–1.84; OR=3.8, 95% CI 2.3–6.1). Self *et al.* [24] found that not using a face covering for all clinical encounters (P=0.012) and a shortage of personal protective equipment (P=0.009) increased the probability of a positive SARS-CoV-2 antibody test in HCWs.

Three studies [14,24,34] found an association between a HCW's self-reported belief of previous SARS-CoV-2 infection (OR 1.23–5.67) and SARS-CoV-2 antibody positivity. Similar results were found for HCWs with a previous positive polymerase chain reaction (PCR) test (OR=1.52, 95% CI 1.44–1.60 in one study [14] and P<0.001 in another study [34]). Also, two studies [18,36] found that household contact with suspected or confirmed cases of COVID-19 increased the probability of a

Table II
Studies that investigated factors associated with severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) antibody positivity among healthcare workers

Reference	Factors investigated for SARS-CoV-2 antibody positivity	Factors associated with SARS-CoV-2 antibody positivity	Level of analysis
Moscola *et al.*, 2020 [14]	Age, sex, race/ethnicity, borough/county of residence, type of occupation, previously diagnosed with COVID-19 by PCR test, self-reported high suspicion of SARS-CoV-2 exposure, primary location of clinical work, direct patient care, working in a COVID-19 unit	– Previous positive PCR test (OR=1.52, 95% CI 1.44–1.60; $P<0.001$) – Self-reported high suspicion of SARS-CoV-2 exposure (OR=1.23, 95% CI 1.18–1.23; $P<0.001$)	Multi-variate
Jeremias *et al.*, 2020 [15]	Sex, ethnicity, type of occupation, primary location of clinical work	– None	Univariate
Steensels *et al.*, 2020 [18]	Age, sex, involvement in clinical care, work during the lockdown phase, involvement in care of patients with COVID-19, exposure to COVID-19-positive coworkers, household contact with suspected or confirmed cases of COVID-19	– Household contact with suspected or confirmed cases of COVID-19 (OR=3.15, 95% CI 2.33–4.25; $P<0.001$)	Multi-variate
Blairon *et al.*, 2020 [19]	Age, sex, type of occupation, level of exposure to patients with COVID-19	– None	Univariate
Korth *et al.*, 2020 [21]	Age, sex, type of occupation, level of exposure to patients with COVID-19	– None	Univariate
Martin *et al.*, 2020 [22]	Age, sex, type of occupation, level of exposure to patients with COVID-19	– None	Univariate
Amendola *et al.*, 2020 [23]	Age, sex, type of occupation, primary location of clinical work	– Surgery department (OR=6.47, 95% CI 2.37–17.63; $P=0.0003$) and paediatric intensive care unit (OR=3.77, 95% CI 1.44–9.89; $P=0.007$)	Univariate
Self *et al.*, 2020 [24]	Age, sex, race/ethnicity, chronic medical conditions, substance use, type of occupation, primary location of clinical work, participants' self-reported belief of previous SARS-CoV-2 infection, face covering for all clinical encounters, participants who reported a shortage of personal protective equipment	– Males (OR=1.39, 95% CI 1.03–1.86, $P=0.029$) – Other participants (Black, Asian, Hispanic etc.) compared with White participants (OR=2.30, 95% CI 1.71–3.10; $P<0.001$) – Participants' self-reported belief of previous SARS-CoV-2 infection (OR=5.67, 95% CI 4.21–7.63; $P<0.001$) – Did not use a face covering for all clinical encounters ($P=0.012$)[a] – Reported a shortage of personal protective equipment ($P=0.009$)[a]	Univariate
Grant *et al.*, 2020 [25]	Prolonged direct contact with patients, working in a COVID-19 unit	– Prolonged direct contact with patients (OR=1.57, 95% CI 1.27–1.93; $P<0.005$) – Working in a COVID-19 unit (OR=1.67, 95% CI 1.40–1.99; $P<0.001$)	Univariate
Hunter *et al.*, 2020 [27]	Age, sex, type of occupation, level of exposure to patients with COVID-19	– None	Univariate
Plebani *et al.*, 2020 [28]	Age, sex, type of occupation	– Aged ≥40 years (OR=1.36, 95% CI 1.09–1.60; $P=0.006$)	Univariate

Table II (*continued*)

Reference	Factors investigated for SARS-CoV-2 antibody positivity	Factors associated with SARS-CoV-2 antibody positivity	Level of analysis
		– Healthcare assistants (OR=1.39, 95% CI 1.05–1.84; *P*=0.02)	
Mansour *et al.*, 2020 [29]	Age, sex	– None	Univariate
Sotgiu *et al.*, 2020 [30]	Age, sex, type of occupation, contact with patients with COVID-19	– Males (OR=3.21, 95% CI 1.43–7.19; *P*=0.003)	Univariate
Garcia-Basteiro *et al.*, 2020 [31]	Age, sex, type of occupation, daily contact with patients, working in a COVID-19 unit, close contact with confirmed or suspected cases of COVID-19, previously diagnosed with COVID-19 by PCR test, comorbidity, household size, flu vaccine	– None	Univariate
Sydney *et al.*, 2020 [32]	Age, sex, race/ethnicity, primary location of clinical work	– African American participants compared with other ethnic groups (*P*<0.05)[a]	Univariate
Stubblefield *et al.*, 2020 [34]	Age, sex, race/ethnicity, comorbidity, smoking, primary location of clinical work, type of occupation, previously diagnosed with COVID-19 by PCR test, face covering for all clinical encounters, participants' self-reported belief of previous SARS-CoV-2 infection	– Participants' self-reported belief of previous SARS-CoV-2 infection (*P*=0.02)[a] – Previous positive PCR test (*P*<0.001)[a]	Univariate
Lackermair *et al.*, 2020 [35]	Age, sex, contact with patients with COVID-19, temporary residence in a high-risk SARS-CoV-2 region	– None	Univariate
Paderno *et al.*, 2020 [36]	Age, sex, type of occupation, hospital and household contacts without personal protective equipment	– Household contacts without personal protective equipment (*P*=0.008)[a]	Univariate
Kassem *et al.*, 2020 [37]	Age, sex, type of occupation	– None	Univariate
Iversen *et al.*, 2020 [39]	Age, sex, comorbidity, smoking, alcohol consumption, type of occupation, working in a COVID-19 unit, patient contact	– Males (OR=1.49, 95% CI 1.31–1.68; *P*<0.001) – Aged <30 years (OR=1.40, 95% CI 1.22–1.60; *P*<0.001) – Working in a COVID-19 unit (OR=1.65, 95% CI 1.34–2.03; *P*<0.001) – Front-line healthcare workers (OR=1.38, 95% CI 1.22–1.56; *P*<0.001) – Regular patient contact (OR=1.22, 95% CI 1.03–1.45; *P*=0.02)	Multi-variate
Fusco *et al.*, 2020 [44]	Age, sex, type of occupation, primary location of clinical work, working in a COVID-19 unit, participation in training event on personal protective equipment	– None	Univariate
Xu *et al.*, 2020 [47]	Age, sex, type of occupation	– Aged ≥65 years (*P*<0.001)[a]	Univariate
Galán *et al.*, 2020 [52]	Age, sex, comorbidity, type of occupation, primary location of clinical work	– None	Univariate
Psichogiou *et al.*, 2020 [54]	Sex, country of birth, education, household size, front-line or second-line HCWs, personal protective equipment	– None	Univariate
Fujita *et al.*, 2020 [58]	Age, sex, type of occupation, primary location of clinical work, history of seasonal common cold symptoms, history of regular	– None	Univariate

(*continued on next page*)

Table II (*continued*)

Reference	Factors investigated for SARS-CoV-2 antibody positivity	Factors associated with SARS-CoV-2 antibody positivity	Level of analysis
	contact with children, history of exposure to a viral infection		
Rudberg *et al.*, 2020 [60]	Age, sex, type of occupation, patient-related work, contact with patients with COVID-19	– Patient-related work (OR=2.9, 95% CI 1.9–4.5; $P<0.001$) – Contact with patients with COVID-19 (OR=1.4, 95% CI 1.1–1.8; $P=0.003$) – Assistant nurses (OR=3.8, 95% CI 2.3–6.1; $P<0.001$)	Univariate
Shields *et al.*, 2020 [61]	Age, sex, ethnicity	– None	Univariate

COVID-19, coronavirus disease 2019; PCR, polymerase chain reaction; CI, confidence interval; OR, odds ratio.
[a] Data not available to calculate OR and CI.

positive SARS-CoV-2 antibody test in HCWs (OR=3.15, 95% CI 2.33–4.25 in one study [18] and $P=0.008$ in another study [36]).

Discussion

To the authors' knowledge, this is the first systematic review and meta-analysis to estimate the overall seroprevalence of SARS-CoV-2 antibodies among HCWs in screening settings. Overall seroprevalence was 8.7%, ranging from 0% to 45.3% between studies. Population-based and community-based studies in the USA showed high variability in the seroprevalence of SARS-CoV-2 antibodies, ranging from 1.1% to 14.4% [63–67]. Similar studies in Europe [68–70] and China [71] found very different seroprevalence in the general population, ranging from 0.23% to 10.9%. These differences in seroprevalence among studies may be attributable to several reasons, such as different study populations, different antibody tests with variation in sensitivity and specificity, different study designs, different lockdown and quarantine measures, and different dates of data collection. Moreover, according to the subgroup analysis, the seroprevalence of SARS-CoV-2 antibodies was higher for studies of poor quality (11.6%) compared with those with moderate quality (8.8%) and good quality (7.9%), indicating that a difference in study quality could also represent a significant reason for a difference in seroprevalence.

Subgroup analysis identified that seroprevalence was higher in studies conducted in North America (12.7%) compared with those conducted in Europe (8.5%), Africa (8.2%) and Asia (4%). This finding is in accordance with a meta-analysis [3] which found that the overall proportion of HCWs who were SARS-CoV-2 positive among all patients with COVID-19 was lower in China (4.2%) than in the USA (17.8%) and Europe (9%). This might be explained by good adherence to infection prevention and control measures and appropriate use of personal protective equipment among HCWs in China. Also, the USA and Europe seemed to be unprepared to handle the surge of patients which led to severe shortages in personal protective equipment, and the USA and most countries in Europe (with significant exceptions such as Germany and Greece) took action too late [72]. For example, according to reports in the UK and Italy, HCWs experienced extreme situations during the COVID-19 pandemic, wearing paper face masks and plastic aprons instead of appropriate masks, visors and gowns [73,74]. In this meta-analysis, seroprevalence in studies in the UK ($N=7$) and Italy ($N=8$) was higher (10.3%) compared with overall seroprevalence (8.4%), and seroprevalence in studies in Germany ($N=5$) and Greece ($N=2$) was lower (2.2%) than overall seroprevalence. On the other hand, China controlled the severe acute respiratory syndrome (SARS) epidemic that broke out in 2003 rapidly and efficiently [75,76], and immediately adopted the lessons learned from the SARS epidemic in the case of the COVID-19 pandemic by applying effective measures (e.g. early case identification and isolation; active large-scale surveillance of individuals including smartphone application, tracing and quarantining of COVID-19 contacts; temperature screening in public places; physical distancing; traveller screening; and street camera system for identification of individuals without a mask or showing symptoms) [71,77,78]. Moreover, some hospitals in China implemented a tactical training protocol for all aspects of COVID-19 that resulted in a very low infection rate among HCWs, including front-line HCWs in Wuhan [79].

Seropositivity was higher for HCWs performing patient-related work [25,39,60] and front-line HCWs [39]. Grant *et al.* [25] and Rudberg *et al.* [60] found that seropositivity of HCWs was much higher compared with the general population in London and Stockholm, respectively, indicating an occupational health risk among HCWs. Several studies emphasized the risk of occupational transmission of SARS-CoV-2 among HCWs, as HCWs are at the front-line response to COVID-19 and are more prone to viral transmission [73,80–84]. Increased HCW exposure to SARS-CoV-2 may be attributable mainly to patient-to-HCW transmission and HCW-to-HCW transmission due to shortages of personal protective equipment, poor adherence to infection prevention and control measures, and space constraints in hospitals. Additionally, SARS-CoV-2 antibody positivity was higher among healthcare assistants [28,60], which supports patient-related transmission of SARS-CoV-2 to HCWs as these HCWs are involved in most near-patient work.

In this systematic review, seroprevalence was higher among HCWs working in COVID-19 units [25,39,60]. It is clear that HCWs with contact with patients with COVID-19 represent a high-risk group for SARS-CoV-2 infection, and this was particularly true during the first months of the COVID-19 pandemic where knowledge, control measures and personal protective equipment were limited. Also, Self *et al.* [24] found that not

using a face covering for all clinical encounters and shortages of personal protective equipment increase the probability of a positive SARS-CoV-2 antibody test in HCWs. Thus, personal protective equipment supplies for HCWs in hospitals are a necessary tool against COVID-19, and universal masking is of utmost importance as it decreases the rate of SARS-CoV-2 infection among HCWs [85]. Optimal personal protective equipment is still unknown, but rigorous application of personal protective equipment measures and absolute adherence to all infection prevention and control measures are crucial to reduce nosocomial transmission of SARS-CoV-2 [86—89]. Interestingly, Grant *et al*. [25] found that seropositivity was lower among HCWs in ICUs. Several reasons could explain this finding, such as the enhanced personal protective equipment for HCWs in ICUs, the fact that intubated patients are ventilated on a closed circuit, and the fact that patients with COVID-19 who require ICU admission are often admitted around day 10 of the natural history of their illness [90], by which point the viral load has usually decreased [91].

According to this review, household contact with a suspected or confirmed case of COVID-19 is associated with a positive SARS-CoV-2 antibody test in HCWs [18,36]. Also, a HCW's self-reported belief of previous SARS-CoV-2 infection was found to be associated with SARS-CoV-2 antibody positivity [14,24,34]. HCWs are exposed to SARS-CoV-2 not only in clinical settings but also at home, in social situations, during joint meals and in office spaces with friends or colleagues. In fact, as community transmission increases, the risk of SARS-CoV-2 exposure for HCWs is higher outside clinical settings through household contacts with cases of COVID-19 or interaction with others in areas with active, unmitigated transmission [92—94].

This review found that a previous positive PCR test increases the probability of a positive SARS-CoV-2 antibody test in HCWs [14,34]. SARS-CoV-2 antibody tests identify previous SARS-CoV-2 infection, but many issues remain controversial. For example, the sensitivity of these tests is low in the first week after symptom onset but increases $\geq$15 days after the onset of symptoms [5]. Also, the duration of antibody increases is unknown as data $>$35 days after symptom onset are very scarce [5]. Moreover, it is currently unknown whether antibody titres correlate with protective immunity against re-infection, and if antibody responses differ significantly in asymptomatic individuals and individuals with mild or severe COVID-19 [95,96]. Variation in the validity of commercial SARS-CoV-2 antibody tests, cross-reactivity between SARS-CoV-2 and other coronaviruses, and confusion regarding the possible role of SARS-CoV-2 antibodies as biomarkers of protective immunity or past infection increase uncertainty about the utility of SARS-CoV-2 antibody tests in clinical practice [5,97,98]. However, SARS-CoV-2 antibody tests are an additional tool against COVID-19, and their utility will be expanded as additional data provide a better understanding of the pros and cons of these tests. Also, universal screening for SARS-CoV-2 in high-risk units in hospitals could help to identify asymptomatic HCWs, resulting in self-isolation for the appropriate time [22].

This review found that seropositivity was higher among African American [32], Black, Asian and Hispanic HCWs compared with White HCWs [24]. This finding was confirmed by studies in general populations where a higher percentage of SARS-CoV-2 antibodies was found among Black [67,99] and Hispanic [67] HCWs. According to the preliminary analysis of Cook *et al*. [100], until 12th April 2020, 106 HCWs died in the UK with COVID-19 and 64.2% (N=68) of them were Black, Asian and Minority Ethnic communities. Moreover, Gould and Wilson [101] found that Black HCWs experienced higher SARS-CoV-2 seroprevalence than White HCWs. Several reasons may be given for this disparity, including work conditions, economic inequality, high population density, limited access to healthcare services, and health insurance. There is a need for strategies tailored to the culture of minority groups and organized by local minority leaders who can mobilize individuals to participate in screening tests, and tracing and quarantining of COVID-19 contacts to avoid additional SARS-CoV-2 infections in minority groups [102].

This review has several limitations. First, 14 of the 49 included studies were published in preprint services which do not apply a peer-review process. Nevertheless, study quality was assessed, and subgroup analysis was performed according to publication type (journal or preprint service) and study quality. Second, the heterogeneity between results was very high. A random effects model and subgroup analysis were applied to overcome this limitation. Third, seroprevalence reported in studies could be underestimated or overestimated depending on the antibody test used. Validity (sensitivity and specificity) of the antibody tests were not reported in most of the included studies. A meta-regression analysis using sensitivity and specificity of the antibody tests according to the manufacturers' data as the moderator variables was performed in order to overcome this limitation. Fourth, the time between exposure and antibody testing in studies is unknown, and seropositivity may have been missed if testing was too early. This systematic bias could result in underestimation of seroprevalence. Finally, data regarding factors associated with seroprevalence of SARS-CoV-2 antibodies were very scarce and it was not possible to perform a meta-analysis; as such, a qualitative approach was applied to assess these factors.

In conclusion, seroprevalence of SARS-CoV-2 antibodies among HCWs is high, indicating that HCWs represent a population at considerable risk of contracting COVID-19. Absolute adherence to infection prevention and control measures; sufficient and adequate personal protective equipment; and early recognition, identification and isolation of HCWs infected with SARS-CoV-2 are imperative to decrease the risk of SARS-CoV-2 infection. Moreover, seroprevalence studies among HCWs could add significant information regarding the level of exposure among HCWs, identification of high-risk departments in hospitals, measurement of the spread of COVID-19, success of interventions, and understanding of asymptomatic transmission of SARS-CoV-2 in clinical settings. Given the limitations of this review and the included studies, and that the COVID-19 pandemic is still evolving, there is a need for further high-quality studies.

Conflict of interest statement
None declared.

Funding sources
None.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jhin.2020.11.008.

References

[1] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020;382:1199—207.

[2] World Health Organization. WHO coronavirus disease (COVID-19) dashboard. Geneva: WHO; 2020. Available at: https://covid19.who.int/ [last accessed October 2020].

[3] Sahu AK, Amrithanand VT, Mathew R, Aggarwal P, Nayer J, Bhoi S. COVID-19 in health care workers — a systematic review and meta-analysis. Am J Emerg Med 2020;38:1727—31.

[4] Xiang B, Li P, Yang X, Zhong S, Manyande A, Feng M. The impact of novel coronavirus SARS-CoV-2 among healthcare workers in hospitals: an aerial overview. Am J Infect Control 2020;48:915—7.

[5] Deeks JJ, Dinnes J, Takwoingi Y, Davenport C, Spijker R, Taylor-Phillips S. Cochrane COVID-19 Diagnostic Test Accuracy Group. Antibody tests for identification of current and past infection with SARS-CoV-2. Cochrane Database Syst Rev 2020;6:CD013652.

[6] Riccò M, Ferraro P, Gualerzi G, Ranzieri S, Henry BM, Said YB, et al. Point-of-care diagnostic tests for detecting SARS-CoV-2 antibodies: a systematic review and meta-analysis of real-world data. J Clin Med 2020;9:1515.

[7] Moher D, Liberati A, Tetzla J, Altman DG, Altman D, Antes G, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA Statement. PLoS Med 2009;6:e1000097.

[8] Santos W, Secoli SR, Püschel V. The Joanna Briggs Institute approach for systematic reviews. Rev Lat Am Enfermagem 2018;26:e3074.

[9] Barendregt JJ, Doi SA, Lee YY, Norman RE, Vos T. Meta-analysis of prevalence. J Epidemiol Community Health 2013;67:974—8.

[10] Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;327:557—60.

[11] Ioannidis JP, Patsopoulos NA, Evangelou E. Heterogeneity in meta-analyses of genome-wide association investigations. PLoS One 2007;2:e841.

[12] Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ 1997;315:629—34.

[13] Wallace BC, Schmid CH, Lau J, Trikalinos TA. Meta-Analyst: software for meta-analysis of binary, continuous and diagnostic data. BMC Med Res Methodol 2009;9:80.

[14] Moscola J, Sembajwe G, Jarrett M, Farber B, Chang T, McGinn T, et al., Northwell Health COVID-19 Research Consortium. Prevalence of SARS-CoV-2 antibodies in health care personnel in the New York City area. JAMA 2020;324:893—5.

[15] Jeremias A, Nguyen J, Levine J, Pollack S, Engellenner W, Thakore A, et al. Prevalence of SARS-CoV-2 infection among health care workers in a tertiary community hospital. JAMA Intern Med 2020. 11:e204214.

[16] Houlihan CF, Vora N, Byrne T, Lewer D, Kelly G, Heaney J, et al. Pandemic peak SARS-CoV-2 infection and seroconversion rates in London frontline health-care workers. Lancet 2020;396:e6—7.

[17] Poulikakos D, Sinha S, Kalra PA. SARS-CoV-2 antibody screening in healthcare workers in a tertiary centre in North West England. J Clin Virol 2020;129:104545.

[18] Steensels D, Oris E, Coninx L, Nuyens D, Delforge ML, Vermeersch P, et al. Hospital-wide SARS-CoV-2 antibody screening in 3056 staff in a tertiary center in Belgium. JAMA 2020;324:195—7.

[19] Blairon L, Mokrane S, Wilmet A, Dessilly G, Kabamba-Mukadi B, Beukinga I, et al. Large-scale, molecular and serological SARS-CoV-2 screening of healthcare workers in a 4-site public hospital in Belgium after COVID-19 outbreak. J Infect 2020;4453:30514-4.

[20] Pallett S, Rayment M, Patel A, Fitzgerald-Smith S, Denny SJ, Charani E, et al. Point-of-care serological assays for delayed SARS-CoV-2 case identification among health-care workers in the UK: a prospective multicentre cohort study. Lancet Respir Med 2020;8:885—94.

[21] Korth J, Wilde B, Dolff S, Anastasiou OE, Krawczyk A, Jahn M, et al. SARS-CoV-2-specific antibody detection in healthcare workers in Germany with direct contact to COVID-19 patients. J Clin Virol 2020;128:104437.

[22] Martin C, Montesinos I, Dauby N, Gilles C, Dahma H, Van Den Wijngaert S, et al. Dynamics of SARS-CoV-2 RT-PCR positivity and seroprevalence among high-risk healthcare workers and hospital staff. J Hosp Infect 2020;106:102—6.

[23] Amendola A, Tanzi E, Folgori L, Barcellini L, Bianchi S, Gori M, et al. Low seroprevalence of SARS-CoV-2 infection among healthcare workers of the largest children hospital in Milan during the pandemic wave. Infect Control Hosp Epidemiol 2020;41:1468—9.

[24] Self WH, Tenforde MW, Stubblefield WB, Feldstein LR, Steingrub JS, Shapiro NI, et al. Seroprevalence of SARS-CoV-2 among frontline health care personnel in a multistate hospital network-13 academic medical centers, April—June 2020. MMWR 2020;69:1221—6.

[25] Grant JJ, Wilmore S, McCann NS, Donnelly O, Lai R, Kinsella MJ, et al. Seroprevalence of SARS-CoV-2 antibodies in healthcare workers at a London NHS trust. Infect Control Hosp Epidemiol 2020;4:1—3.

[26] Mughal MS, Kaur IP, Patton CD, Mikhail NH, Vareechon C, Granet KM. The prevalence of severe acute respiratory coronavirus virus 2 (SARS-CoV-2) IgG antibodies in intensive care unit (ICU) healthcare personnel (HCP) and its implications — a single-center, prospective, pilot study. Infect Control Hosp Epidemiol 2020;12:1—2.

[27] Hunter E, Price DA, Murphy E, van der Loeff IS, Baker KF, Lendrem D, et al. First experience of COVID-19 screening of health-care workers in England. Lancet 2020;395:e77—8.

[28] Plebani M, Padoan A, Fedeli U, Schievano E, Vecchiato E, Lippi G, et al. SARS-CoV-2 serosurvey in health care workers of the Veneto region. Clin Chem Lab Med 2020;58:2107—11.

[29] Mansour M, Leven E, Muellers K, Stone K, Mendu DR, Wajnberg A. Prevalence of SARS-CoV-2 antibodies among healthcare workers at a tertiary academic hospital in New York City. J Gen Intern Med 2020;35:2485—6.

[30] Sotgiu G, Barassi A, Miozzo M, Saderi L, Piana A, Orfeo N, et al. SARS-CoV-2 specific serological pattern in healthcare workers of an Italian COVID-19 forefront hospital. BMC Pulm Med 2020;20:203.

[31] Garcia-Basteiro AL, Moncunill G, Tortajada M, Vidal M, Guinovart C, Jiménez A, et al. Seroprevalence of antibodies against SARS-CoV-2 among health care workers in a large Spanish reference hospital. Nat Commun 2020;11:3500.

[32] Sydney E, Kishore P, Laniado I, Rucker L, Bajaj K, Zinaman M. Antibody evidence of SARS-CoV-2 infection in healthcare workers in the Bronx. Infect Control Hosp Epidemiol 2020;41:1348—9.

[33] Khalil A, Hill R, Wright A, Ladhani S, O'Brien P. SARS-CoV-2-specific antibody detection in healthcare workers in a UK maternity hospital: correlation with SARS-CoV-2 RT-PCR results. Clin Infect Dis 2020; 8:ciaa893.

[34] Stubblefield WB, Talbot HK, Feldstein L, Tenforde MW, Rasheed M, Mills L, et al. Seroprevalence of SARS-CoV-2 among frontline healthcare personnel during the first month of caring for COVID-19 patients — Nashville, Tennessee. Clin Infect Dis 2020; 6:ciaa936.

[35] Lackermair K, William F, Grzanna N, Lehmann E, Fichtner S, Kucher HB, et al. Infection with SARS-CoV-2 in primary care health care workers assessed by antibody testing. Fam Pract 2020; 7:cmaa078.

[36] Paderno A, Fior M, Berretti G, Schreiber A, Grammatica A, Mattavelli D, et al. SARS-CoV-2 infection in health care workers:

cross-sectional analysis of an otolaryngology unit. Otolaryngol Head Neck Surg 2020;163:671—2.
[37] Kassem AM, Talaat H, Shawky S, Fouad R, Amer K, Elnagdy T, et al. SARS-CoV-2 infection among healthcare workers of a gastroenterological service in a tertiary care facility. Arab J Gastroenterol 2020;21:151—5.
[38] Olalla J, Correa AM, Martín-Escalante MD, Hortas ML, Martin-Sendarrubias MJ, Fuentes V, et al. Search for asymptomatic carriers of SARS-CoV-2 in healthcare workers during the pandemic: a Spanish experience. QJM 2020; 10:hcaa238.
[39] Iversen K, Bundgaard H, Hasselbalch RB, Kristensen JH, Nielsen PB, Pries-Heje M, et al. Risk of COVID-19 in health-care workers in Denmark: an observational cohort study. Lancet Infect Dis 2020;20:1401—8.
[40] Hains DS, Schwaderer AL, Carroll AE, Starr MC, Wilson AC, Amanat F, et al. Asymptomatic seroconversion of immunoglobulins to SARS-CoV-2 in a pediatric dialysis unit. JAMA 2020;323:2424—5.
[41] Solodky ML, Galvez C, Russias B, Detourbet P, N'Guyen-Bonin V, Herr AL, et al. Lower detection rates of SARS-COV2 antibodies in cancer patients versus health care workers after symptomatic COVID-19. Ann Oncol 2020;31:1087—8.
[42] Behrens G, Cossmann A, Stankov MV, Witte T, Ernst D, Happle C, et al. Perceived versus proven SARS-CoV-2-specific immune responses in health-care professionals. Infection 2020;48:631—4.
[43] Brandstetter S, Roth S, Harner S, Buntrock-Döpke H, Toncheva AA, Borchers N, et al. Symptoms and immunoglobulin development in hospital staff exposed to a SARS-CoV-2 outbreak. Pediatr Allergy Immunol 2020;31:841—7.
[44] Fusco FM, Pisaturo M, Iodice V, Bellopede R, Tambaro O, Parrella G, et al. COVID-19 among healthcare workers in a specialist infectious diseases setting in Naples, Southern Italy: results of a cross-sectional surveillance study. J Hosp Infect 2020;105:596—600.
[45] Lahner E, Dilaghi E, Prestigiacomo C, Alessio G, Marcellini L, Simmaco M, et al. Prevalence of SARS-CoV-2 infection in health workers (HWs) and diagnostic test performance: the experience of a teaching hospital in central Italy. Int J Environ Res Public Health 2020;17:4417.
[46] Schmidt SB, Grüter L, Boltzmann M, Rollnik JD. Prevalence of serum IgG antibodies against SARS-CoV-2 among clinic staff. PLoS One 2020;15:e0235417.
[47] Xu X, Sun J, Nie S, Li H, Kong Y, Liang M, et al. Seroprevalence of immunoglobulin M and G antibodies against SARS-CoV-2 in China. Nat Med 2020;26:1193—5.
[48] Zhao R, Li M, Song H, Chen J, Ren W, Feng Y, et al. Early detection of SARS-CoV-2 antibodies in COVID-19 patients as a serologic marker of infection. Clin Infect Dis 2020;71:2066—72.
[49] Fernández-Rivas G, Quirant-Sánchez B, González V, Doladé M, Martinez-Caceres E, Piña M, et al. Seroprevalence of SARS-CoV-2 IgG specific antibodies among healthcare workers in the northern metropolitan area of Barcelona, Spain, after the first pandemic wave. medRxiv 2020. 06.24.20135673.
[50] Kammon AM, El-Arabi AA, Erhouma EA, Mehemed TM, Mohamed OA. Seroprevalence of antibodies against SARS-CoV-2 among public community and health-care workers in Alzintan City of Libya. medRxiv 2020. 05.25.20109470.
[51] Xiong S, Guo C, Dittmer U, Zheng X, Wang B. The prevalence of antibodies to SARS-CoV-2 in asymptomatic healthcare workers with intensive exposure to COVID-19. medRxiv 2020; 05.28.20110767.
[52] Galán I, Velasco M, Casas ML, Goyanes MJ, Rodriguez-Caravaca G, Losa JE, et al. SARS CoV-2 seroprevalence among all workers in a teaching hospital in Spain: unmasking the risk. medRxiv 2020. 05.29.20116731.
[53] Nakamura A, Sato R, Ando S, Oana N, Nozaki E, Endo H, et al. Seroprevalence of antibodies to SARS-CoV-2 in healthcare workers in non-epidemic region: a hospital report in Iwate Prefecture, Japan. medRxiv 2020. 06.15.20132316.
[54] Psichogiou M, Karabinis A, Pavlopoulou I, Basoulis D, Petsios K, Roussos S, et al. Antibodies against SARS-CoV-2 among health care workers in a country with low burden of COVID-19. PLoS One 2020;15:e0243025
[55] Chibwana MG, Jere KC, Kamngona R, Mandolo J, Katunga-Phiri V, Tembo D, et al. High SARS-CoV-2 seroprevalence in health care workers but relatively low numbers of deaths in urban Malawi. medRxiv 2020. 07.30.20164970.
[56] Tosato F, Pelloso M, Gallo N, Giraudo C, Llanaj G, Cosma C, et al. Severe acute respiratory syndrome coronavirus 2 serology in asymptomatic healthcare professionals: preliminary experience of a tertiary Italian academic center. medRxiv 2020. 04.27.20073858.
[57] Paradiso AV, De Summa S, Silvestris N, Tommasi S, Tufaro A, De Palma G, et al. COVID-19 screening and monitoring of asymptomatic health workers with a rapid serological test. medRxiv 2020. 05.05.20086017.
[58] Fujita K, Kada S, Kanai O, Hata H, Odagaki T, Satoh-Asahara N, et al. Quantitative SARS-CoV-2 antibody screening of healthcare workers in the southern part of Kyoto city during the COVID-19 peri-pandemic period. Front Public Health 2020;8:595348.
[59] Sikora K, Barwick I, Hamilton C. Serological prevalence of antibodies to SARS CoV-2 amongst cancer centre staff. medRxiv 2020. 05.16.20099408.
[60] Rudberg AS, Havervall S, Manberg A, Falk AJ, Aguilera K, Ng H, et al. SARS-CoV-2 exposure, symptoms and seroprevalence in health care workers. medRxiv 2020. 06.22.20137646.
[61] Shields AM, Faustini SE, Perez-Toledo M, Jossi S, Aldera EL, Allen JD, et al. SARS-CoV-2 seroconversion in health care workers. medRxiv 2020. 05.18.20105197.
[62] Takita M, Matsumura T, Yamamoto K, Yamashita E, Hosoda K, Hamaki T, et al. Preliminary results of seroprevalence of SARS-CoV-2 at community clinics in Tokyo. medRxiv 2020. 04.29.20085449.
[63] Bendavid E, Mulaney B, Sood N, Shah S, Ling E, Bromley-Dulfano R, et al. COVID-19 antibody seroprevalence in Santa Clara County, California. medRxiv 2020. 04.14.20062463.
[64] Sood N, Simon P, Ebner P, Eichner D, Reynolds J, Bendavid E, et al. Seroprevalence of SARS-CoV-2-specific antibodies among adults in Los Angeles County, California, on April 10—11, 2020. JAMA 2020;323:2425—7.
[65] Rosenberg ES, Tesoriero JM, Rosenthal EM, Chung R, Barranco M, Styer LM, et al. Cumulative incidence and diagnosis of SARS-CoV-2 infection in New York. Ann Epidemiol 2020;48:23—9.
[66] Biggs HM, Harris JB, Breakwell L, Dahlgren FS, Abedi GR, Szablewski CM, et al. Estimated community seroprevalence of SARS-CoV-2 antibodies — two Georgia counties, April 28—May 3, 2020. MMWR 2020;69:965—70.
[67] Menachemi N, Yiannoutsos CT, Dixon BE, Duszynski TJ, Fadel WF, Wools-Kaloustian KK, et al. Population point prevalence of SARS-CoV-2 infection based on a statewide random sample — Indiana, April 25—29, 2020. MMWR 2020;69:960—4.
[68] Stringhini S, Wisniak A, Piumatti G, Azman AS, Lauer SA, Baysson H, et al. Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based study. Lancet 2020;396:313—9.
[69] Pollán M, Pérez-Gómez B, Pastor-Barriuso R, Oteo J, Hernán MA, Pérez-Olmeda M, et al. Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study. Lancet 2020;396:535—44.
[70] Bogogiannidou Z, Vontas A, Dadouli K, Kyritsi MA, Soteriades S, Nikoulis DJ, et al. Repeated leftover serosurvey of SARS-CoV-2 IgG antibodies, Greece, March and April 2020. Euro Surveill 2020;25:2001369.

[71] Xu T, Ao M, Zhou X, Zhu WF, Nie HN, Fang JH, et al. China's practice to prevent and control COVID-19 in the context of large population movement. Infect Dis Poverty 2020;9:115.
[72] Pearce N, Lawlor DA, Brickley EB. Comparisons between countries are essential for the control of COVID-19. Int J Epidemiol 2020;49:1059—62.
[73] Hunter DJ. Covid-19 and the stiff upper lip — the pandemic response in the United Kingdom. N Engl J Med 2020;16:382.
[74] Rosenbaum L. Facing Covid-19 in Italy — ethics, logistics, and therapeutics on the epidemic's front line. N Engl J Med 2020;14:382.
[75] Ahmad A, Krumkamp R, Reintjes R. Controlling SARS: a review on China's response compared with other SARS-affected countries. Trop Med Int Health 2009;14:36—45.
[76] Pang X, Zhu Z, Xu F, Guo J, Gong X, Liu D, et al. Evaluation of control measures implemented in the severe acute respiratory syndrome outbreak in Beijing, 2003. JAMA 2003;290:3215—21.
[77] Prem K, Liu Y, Russell TW, Kucharski AJ, Eggo RM, Davies N, et al. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. Lancet Public Health 2020;5:e261—70.
[78] Cyranoski D. What China's coronavirus response can teach the rest of the world. Nature 2020;579:479—80.
[79] Yang DY, Cheng SY, Wang SZ, Wang JS, Kuang M, Wang TH, et al. Preparedness of medical education in China: lessons from the COVID-19 outbreak. Med Teach 2020;42:787—90.
[80] Canova V, Lederer Schlapfer H, Piso RJ, Droll A, Fenner L, Hoffmann T, et al. Transmission risk of SARS-CoV-2 to healthcare workers — observational results of a primary care hospital contact tracing. Swiss Med Wkly 2020;150:w20257.
[81] Banik RK, Ulrich AK. Evidence of short-range aerosol transmission of SARS-CoV-2 and call for universal airborne precautions for anesthesiologists during the COVID-19 pandemic. Anesth Analg 2020;131:e102—4.
[82] Wilson NM, Norton A, Young FP, Collins DW. Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: a narrative review. Anaesthesia 2020;75:1086—95.
[83] McMichael TM, Currie DW, Clark S, Pogosjans S, Kay M, Schwartz NG, et al. Epidemiology of Covid-19 in a long-term care facility in King County, Washington. N Engl J Med 2020;21:382.
[84] Godderis L, Boone A, Bakusic J. COVID-19: a new work-related disease threatening healthcare workers. Occup Med 2020;70:315—6.
[85] Wang X, Ferro EG, Zhou G, Hashimoto D, Bhatt DL. Association between universal masking in a health care system and SARS-CoV-2 positivity among health care workers. JAMA 2020;324:703—4.
[86] Schwartz J, King CC, Yen MY. Protecting health care workers during the coronavirus disease 2019 (COVID-19) outbreak: lessons from Taiwan's severe acute respiratory syndrome response. Clin Infect Dis 2020;71:858—60.
[87] Verbeek JH, Ijaz S, Mischke C, Ruotsalainen JH, Mäkelä E, Neuvonen K, et al. Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff. Cochrane Database Syst Rev 2016;4:CD011621.
[88] Chang D, Xu H, Rebaza A, Sharma L, Dela Cruz CS. Protecting health-care workers from subclinical coronavirus infection. Lancet Respir Med 2020;8:e13.
[89] Wang J, Zhou M, Liu F. Reasons for healthcare workers becoming infected with novel coronavirus disease 2019 (COVID-19) in China. J Hosp Infect 2020;105:100—1.
[90] Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet 2020;395:1054—62.
[91] Bullard J, Dust K, Funk D, Strong JE, Alexander D, Garnett L, et al. Predicting infectious SARS-CoV-2 from diagnostic samples. Clin Infect Dis 2020; 22:ciaa638.
[92] Belingheri M, Paladino ME, Riva MA. Beyond the assistance: additional exposure situations to COVID-19 for healthcare workers. J Hosp Infect 2020;105:353.
[93] Muhi S, Irving LB, Buising KI. COVID-19 in Australian healthcare workers: early experience of the Royal Melbourne Hospital emphasises the importance of community acquisition. Med J Aust 2020;213:44.
[94] Liu J, Ouyang L, Guo P, Wu H, Fu P, Chen Y, et al. Epidemiological, clinical characteristics and outcome of medical staff infected with COVID-19 in Wuhan, China: a retrospective case series analysis. medRxiv 2020. 03.09.20033118.
[95] Zohar T, Alter G. Dissecting antibody-mediated protection against SARS-CoV-2. Nat Rev Immunol 2020;20:392—4.
[96] Döhla M, Boesecke C, Schulte B, Diegmann C, Sib E, Richter E, et al. Rapid point-of-care testing for SARS-CoV-2 in a community screening setting shows low sensitivity. Public Health 2020;182:170—2.
[97] Iyer AS, Jones FK, Nodoushani A, Kelly M, Becker M, Slater D, et al. Dynamics and significance of the antibody response to SARS-CoV-2 infection. medRxiv 2020. 07.18.20155374.
[98] Theel ES, Slev P, Wheeler S, Couturier MR, Wong SJ, Kadkhoda K. The role of antibody testing for SARS-CoV-2: is there one? J Clin Microbiol 2020;58. e00797-20.
[99] Stokes EK, Zambrano LD, Anderson KN, Marder EP, Raz KM, Felix S, et al. Coronavirus disease 2019 case surveillance — United States, January 22—May 30, 2020. MMWR 2020;69:759—65.
[100] Cook T, Kursumovic E, Lennane S. Exclusive: deaths of NHS staff from COVID-19 analysed. HSJ; 2020. Available at: https://www.hsj.co.uk/exclusive-deaths-of-nhs-staff-from-covid-19-analysed/7027471 [last accessed October 2020].
[101] Gould E, Wilson V. Black workers face two of the most lethal preexisting conditions for coronavirus — racism and economic inequality. Economic Policy Institute; 2020. Available at: https://www.epi.org/publication/black-workers-covid [last accessed October 2020].
[102] Novacek DM, Hampton-Anderson JN, Ebor MT, Loeb TB, Wyatt GE. Mental health ramifications of the COVID-19 pandemic for black Americans: clinical and research recommendations. Psychol Trauma 2020;12:449—51.