SARS-CoV-2 seroprevalence around the world: an updated systematic review and meta-analysis

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Abstract
Background: Covid-19 has been one of the major concerns around the world in the last 2 years. One of the challenges of this disease has been to determine its prevalence. Conflicting results of the serology test in Covid explored the need for an updated meta-analysis on this issue. Thus, this systematic review aimed to estimate the prevalence of global SARS-CoV-2 serology in different populations and geographical areas.

Methods: To identify studies evaluating the seroprevalence of SARS-CoV-2, a comprehensive literature search was performed from international databases, including Medline (PubMed), Web of Sciences, Scopus, EMBASE, and CINHAL.

Results: In this meta-analysis, the results showed that SARS-CoV-2 seroprevalence is between 3 and 15% worldwide. In Eastern Mediterranean, the pooled estimate of seroprevalence SARS-CoV-2 was 15% (CI 95% 5–29%), and in Africa, the pooled estimate was 6% (CI 95% 1–13%). In America, the pooled estimate was 8% (CI 95% 6–11%), and in Europe, the pooled estimate was 5% (CI 95% 4–6%). Also, the last region, Western Pacific, the pooled estimate was 3% (CI 95% 2–4%). Besides, we analyzed three of these areas separately. This analysis estimated the prevalence in subgroups such as study population, diagnostic methods, sampling methods, time, perspective, and type of the study.

Conclusion: The present meta-analysis showed that the seroprevalence of SARS-CoV-2 has been between 3 and 15% worldwide. Even considering the low estimate of this rate and the increasing vaccination in the world, many people are still susceptible to SARS-CoV-2.

Keywords: Covid-19, SARS-CoV-2, Global seroprevalence, Serum antibodies (IgG and/or IgM), Systematic review, Meta-analysis

Background
Scientists first reported infection due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in Wuhan, China, in December 2019 [1], and due to its contagious nature, it rapidly spread throughout China and the world as the WHO declared a pandemic on March 11, 2020 [2, 3]. According to the World Health Organization (WHO), more than 220 million cases have been identified worldwide; more than 5 million have died [4]. The presented statistics show only a part of the total cases because the clinical manifestations of patients with SARS-CoV-2 vary from acute diseases with severe pneumonia, acute respiratory distress syndrome, or multiple organ failure up to asymptomatic infection. Asymptomatic carriers are essential sources of the infection spread during the incubation period and interfere with the prevention and control of the disease. So, this group of people is an important challenge in the current management of the pandemic [5–7].

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The ideal method for detecting Covid-19 is a real-time reverse transcription-polymerase chain reaction (RT-PCR). Still, the disease may not be detectable for various reasons, including low viral concentrations in the upper respiratory tract, non-standard sampling methods, and reduced viral load one week after the onset of symptoms. False-negative results may be reported [3, 8]. However, because SARS-COV-2 infection can induce innate and acquired immunity, resulting in widespread inflammatory responses in the disease [9], and neutralizing antibodies (Nabs) made against spike glycoprotein or SARS-CoV-2 nucleocapsid protein are often lead to a long-term immune response in viral infections which in most patients with different titers can be detected within 14 to 21 days after the onset of symptoms and at least for several months thereafter [8, 10], the method of serological testing replaces and complements molecular testing by detecting virus-specific antibodies in blood samples such as IgM and IgG and through commercially available tests including lateral flow immunoassays (LFIA), enzyme-linked immunoassays (ELISAs), fluorescence immunoassays (FIA), chemiluminescence assays (CLIA), electro-chemiluminescent immunoassay (ECLIA), and pseudovirus neutralization assays (PsVN assay or VN), and it is used to estimate the serum prevalence in the population and thus the total number of previous infections to diagnose asymptomatic cases, post-clinical convalescence, post-vaccine responses and as a diagnostic aid method in false-negative cases reported by PCR [11–13].

To date, epidemiologists from many countries conducted seroprevalence studies on different populations. The results are significantly different between studies, and in many cases, the actual number of patients is higher than the recorded cases. Therefore, they cannot be the exact measure of serum prevalence in the general population and the true extent of pandemic dynamics. As a result, differences in the presented statistics can lead to inappropriate policies and harm to public health [7, 8, 10]. Because Covid-19 has become a global threat and its spread depends on social interactions, population density, education, health promotion, and other related factors, determining the prevalence of infection and collective immunity against SARS-CoV-2 and the use of these data are necessary for making decisions about control measures, management, and assessment of epidemic risks. Therefore, in this meta-analysis, we aimed to estimate the prevalence of global SARS-CoV-2 serology in different populations and geographical areas and investigate the factors affecting it.

Methods
This systematic review and meta-analysis were based on PRISMA guidelines which are specific to the systematic review and meta-analysis of observational studies [14, 15].

Search strategy
All original articles published from December 2019 to December 2021 were searched without language restrictions in international databases, including Medline (PubMed), Web of Sciences, Scopus, EMBASE, and CINHAL. The search strategy in this study was performed using the main study keywords, including serologic tests (with synonyms of serologic, serology, serology studies) SARS-CoV-2 (with synonyms of Covid-19).

Gray Literature was then searched to access unpublished articles and dissertations or international reports. In addition, after the final selection of articles, a manual search was performed by reviewing the references of related articles. Also, medrxiv and bioRxiv websites were used for findings preprint studies related to seroprevalence of SARS-CoV-2 from inception to December 2021.

Study selection and eligibility criteria
The search strategy in international databases was independently performed by the two researchers (MA and AM), and the disputes were resolved by the third person (YM).

Inclusion criteria
In this meta-analysis, studies were considered whose main purpose was to determine the prevalence of positive serological tests in different communities; that is, after performing tests at different times in other communities, the prevalence of the number of positive tests was examined. Therefore, cohort and cross-sectional studies were included in this meta-analysis. The statistical population studied in these initial articles were all individuals, whether with a specific disease or healthy. There were no particular restrictions on the method of serological diagnosis of Covid-19 in this study for inclusion of studies, and various serological tests such as ELISA, LFIA, VN, CLIA, and ECLIA were included in the research. The definition of Covid-19 disease in this study was based on its international definition affected by the transmission of the SARS-CoV-2 virus.
Exclusion criteria
Other studies, including case reports or case series, systematic reviews, and meta-analyses, as well as letters or editorials, were excluded from this study.

Data extraction
To extract information, first, a checklist including questions on the first author’s name, date of publication, country, WHO region, type of sampling (random or non-random), duration of the study, type of the serological test, race, and ethnicity, age, gender (male, and female), number of positive tests and number of performed tests was designed. Then, information extraction based on the checklist was independently performed by the two authors (AM and MA), and disputes, if any, were resolved by the third person (YM).

Quality assessment
In this study, to evaluate the quality of included articles, the Joanna Briggs Institute (JBI) critical appraisal checklist was used for observational studies. JBI critical appraisal tools have been developed by the JBI and collaborators and approved by the JBI Scientific Committee following extensive peer review.

Statistical analysis
According to the extracted information, the Metaprop command was used to calculate the pooled prevalence,
Table 1  Characteristics of included studies

| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|-----------------|---------------------|------------------|-----------------------------------------|--------------|---------------------------|---------------|--------|-----|-------------------------------|-------------------------------|---------------------|
| Herzog et al. [40] | Belgium (European Region) | Individuals aged 0–101 years | Random | March–July, 2020 | ELISA |                          | 1799 (46.0%) | Highest % | 60–70Y | 507 (13.0%) | 30 March–5 April 113 | 16,532 | 840 |
|                  |                     |                  |                                         |              |                           |               |         | 10–20Y | 442 (13.0%) | 20–26 April 204 |                           |                     |
|                  |                     |                  |                                         |              |                           |               |         | 10–20Y | 431 (13.3%) | 18–26 May 224 |                           |                     |
|                  |                     |                  |                                         |              |                           |               |         | 60–70Y | 399 (13.5%) | 8–13 June 163 |                           |                     |
|                  |                     |                  |                                         |              |                           |               |         | 10–20Y | 413 (13.7%) | 29 June–4 July 136 |                           |                     |
| Filho et al. [41] | Brazil (Region of the Americas) | Blood donors in Rio de Janeiro | Non-random | April, 2020 | LFIA |                          | 1450 | Highest % | 30–49Y | 1443 (3.7%) | 2857 | 114 (4.0%) |
| Silveira et al. [42] | Brazil (region of the Americas) | Individuals in Canoas, Caxias do Sul, Ijuí, Passo Fundo, Pelotas, Porto Alegre, Santa Cruz do Sul, Santa Maria and Uruguaiana | Random (multi-stage sampling) | March–May, 2020 | LFIA |                          | 41.1% | Highest % | 50–59 | 17.1% | 4500 | 18 |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|------------------------------------------|--------------|---------------------------|---------------|--------|-----|-------------------------------------|---------------------------------|--------------------------|
| Torres et al. [43] | Chile (Region of the Americas) | Large School Community Subject | Non-random | April, 2020 | LFIA | Students 54% | Mean 10.8 | 1009 | 100 |                                    | 235 | 39          |
| Chang et al. [44] | China (Western Pacific Region) | Blood donors in the cities of Wuhan, Shenzhen, and Shijiazhuang among 18–60-year-old adults | Non-random | January–April, 2020 | VN | Wuhan Han 17,126 (96.2) | Median 33 | 11,077 | 62.3 |                              | 17,794 | 515         |
|                     |                     |                  |                                          |              |              | Non-Han: 533 (3.0) |                           |                      |                  |                          |                     |             |
|                     |                     |                  |                                          |              |              | Missing data: 135 (0.8) |                           |                      |                  |                          |                     |             |
|                     |                     |                  |                                          |              |              | Shenzhen Han 6519 (95.7) | 36 | 4428 | 65.0 |                              | 6810 | 3           |
|                     |                     |                  |                                          |              |              | Non-Han: 274 (4.0) |                           |                      |                  |                          |                     |             |
|                     |                     |                  |                                          |              |              | Missing data: 17 (0.2) |                           |                      |                  |                          |                     |             |
|                     |                     |                  |                                          |              |              | Shijiazhuang Han 13,414 (99.1) | 40 | 9542 | 70.5 |                              | 13,540 | 1           |
|                     |                     |                  |                                          |              |              | Non-Han: 124 (0.9) |                           |                      |                  |                          |                     |             |
|                     |                     |                  |                                          |              |              | Missing data: 2 (0.0) |                           |                      |                  |                          |                     |             |
| To et al. [45] | China (Western Pacific Region) | In a hospital and university in Hong Kong | Random | December, 2019-February, 2020 | ELISA | SERP | Median 59 | 1214 | 29 |                              | 1214 | 29          |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|--------------------------|---------------|--------|-----|-------------------------------------|-------------------------------|--------------------------|
| Liang et al. [46] | China (Western Pacific Region) | Hospital visitors | Random | January–April, 2020 | CLIA | Wuhan 41 (50.0) Guangzhou 42 (49.7) | Male | Median 55 | 63 | 8272 | 174 |
| Jerković et al. [47] | Croatia (European Region) | In industry workers in Split-Dalmatia and Šibenik-Knin | Non-random | April, 2020 | LFIA | Split-Dalmatia | Male | Median 46 | 1316 | 13 | 8782 | 53 |
| Erikstrup et al. [48] | Denmark (European Region) | Blood donors aged 17–69 years | Non-random | April–May, 2020 | LFIA | Knin | Median 54 | 1316 | 13 | 20,640 | 412 |
| Petersen et al. [49] | Denmark (European Region) | Individuals in Faroe Islands | Random | April–May, 2020 | ELISA | White: 92,737 Mixed: 13,947 | Female | Median 42 | 10,75 | 6 | 99,908 | 5,544 |
| Ward et al. [50] | England (European Region) | Age 18+ years in England | Non-random | June–July, 2020 | LFIA | White: 92,737 Mixed: 13,947 Asian: 36,58 Black: 900 Other: 762 | Male | Median 41 | 998 | 27 |
| Gallian et al. [51] | France (European Region) | In group O French blood donors | Non-random | March–April, 2020 | VN | | Female | Median 41 | 998 | 27 |
| Grzelak et al. [52] | France (European Region) | Hospitalized patients, pauci-symptomatic individuals and blood donors | Random | March, 2020 | ELISA | | Female | Median 18 | 200 | 3 |
| Fischer et al. [53] | Germany (European Region) | In blood donors located in three different federal states | Non-random | March–June, 2020 | ELISA | | | | 3186 | 29 |
| Weis et al. [54] | Germany (European Region) | Individuals in the CoNAN study | Non-random | May, 2020 | ELISA | | | | 562 | 51 |
| Bogogian-nidou et al. [55] | Greece (European Region) | People by using the leftover sampling methodology | Random | March–April, 2020 | CLIA | | | | 6586 | 24 |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|--------------------------|----------------|--------|-----|------------------------------------------|-------------------------------|--------------------------|
| Merkely et al. [56] | Hungary (European Region) | Hungarian population included individuals aged 14 years or older, living in private households | Random | May, 2020 | CLIA | 486 | Mean 48.7 | 10,474 | 69 |
| Shakiba et al. [57] | Iran (Eastern Mediterranean Region) | Individuals in Guilan province, Iran | Random | April, 2020 | LFIA | 270(49) | Highest % 18–60 343 | 551 | 117 |
| Percivalle et al. [58] | Italy (European Region) | In blood donors from the Lodi Red Zone in Lombardy, Italy | Non-random | January–February, 2020 | VN | 272 (70%) | Median 43 | 390 | 91 |
| Valenti et al. [59] | Italy (European Region) | Blood donors during the COVID-19 Milan outbreak | Random | February–April, 2020 | LFIA | 453 | Mean 40.7 | 729 | 40 |
| Fiore et al. [60] | Italy (European Region) | In healthy blood donors in South Eastern Italy | Random | May, 2020 | CLIA | 665 | Highest % 46–55 246 | 904 | 9 |
| Doi et al. [61] | Japan (Western Pacific Region) | Individuals in Kobe, Japan | Random | March–April, 2020 | LFIA | 486 | Highest % 60–69 171 | 1000 | 33 |
| Takita et al. [62] | Japan (Western Pacific Region) | Individuals in primary care clinics in Tokyo, Japan | Random | March–April, 2020 | LFIA | 461 | Highest % 35–54 653 | 1071 | 41 |
| Takita et al. [63] | Japan (Western Pacific Region) | Individuals at community clinics in Tokyo Authors: | Non-random | April–May, 2020 | LFIA | 87 (59%) | Highest % 40–49 58 (39) | 147 | 7 |
| Uyoga et al. [64] | Kenya (African Region) | In Kenyan blood donors | Random | April–June, 2020 | ELISA | 2540 | Highest % 25 to 34 1242 | 3098 | 174 |
| Authors (years) (R) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|---------------------|---------------------|------------------|----------------------------------------|--------------|--------------------------|---------------|--------|-----|--------------------------------------|----------------------------------|--------------------------|
| Song et al. [65]    | Korea (Western Pacific Region) | Individuals without a history of the coronavirus disease infection in Daegu, Korea | Random | May–June, 2020 | LFIA | 99 (50%) | Highest % | 40–59 | 89 |                                | 198                              | 15 (7.6)                |
| Kammon et al. [66]  | Libya (African Region) | Among public community and health-care workers in Alzintan City of Libya | Random | April–May, 2020 | LFIA | 103 | | | | 130                              | 6                               |
| Snoeck et al. [67]  | Luxembourg (European Region) | In the Luxembourghish population—the CON-VINCE study | Random | April–May, 2020 | ELISA | 911 (48.93) | Mean 47 | | | 1862                              | 35                              |
| Sam et al. [68]     | Malaysia (Western Pacific Region) | Individuals in Kuala Lumpur and Selangor, Malaysia | Random | January–June, 2020 | VN | 448 | | | | 816                              | 3                               |
| Pollán et al. [7]   | Spain (European Region) | Spain population | Random | April–May, 2020 | LFIA | Spanish: 57,838 | 29 349 | Highest % | 50–64 ≥ 65 | 15 094 | 61,075 | 3054 |
| Lundkvist et al. [69] | Sweden (European Region) | Two areas in Stockholm with different socio-economic conditions | Random | June, 2020 | LFIA | Sweden as country of origin (%) | Djurgårds-staden 42% Tensta 71% | Mean 37 | | | 123 | 5 |
| Stringhini et al. [70] | Switzerland (European Region) | Former participants of the Bus Santé study and their household members | Random | April–May, 2020 | ELISA | 1312 | Highest % | 20–49 (n = 1096) | | | 2766 | 219 |
### Table 1 (continued)

| Authors (year) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on month) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|-----------------------------------------|--------------|----------------------------|----------------|--------|-----|--------------------------------------|----------------------------------|--------------------------|
| Bendavid et al. [71] | USA (Region of the Americas) | Adults and children in Santa Clara County | Random | April, 2020 | LFIA | Non-Hispanic 21/16 White 6/3 Hispanic 26/6 Asian Other 3/0 | Male 12/28 36.9% | Male | Highest | 40–69 17/06 | 3330 | 50 |
| Biggs et al. [72] | USA (Region of the Americas) | The Georgia shelter-in-place order for all residents (April 3–30) | Non-random | April–May, 2020 | CLIA | White, non-Hispanic 3/29 Black, non-Hispanic 2/66 Hispanic 4/4 Asian/Pacific Islander, non-Hispanic 2/9 Multiple race/ Other/ Unknown 2/8 | Male 31/7 | Male | Highest | 18–49 3/47 | 696 | 19 |
| Bryan et al. [73] | USA (Region of the Americas) | Individuals in Boise, Idaho | Random | April, 2020 | CLIA | White 3/15 (41.9) Hispanic 1/3 Black 3/4 White 3/36 (41.4) Hispanic 3/6 Other 3/86 (10.6) | Male | Male | Highest | 1,142 (23.5) | 4856 | 87 |
| Dietrich et al. [74] | USA (Region of the Americas) | Children in Louisiana During the Stay at Home Order | Random | March–May, 2020 | ELISA | Black 1/03 (49.6%) White 3/36 (41.4) Hispanic 3/6 Other 86 (10.6) | Male | Male | Median | 11 | 812 | 62 |
### Table 1 (continued)

| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender Male | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|-----------------|----------------------|------------------|----------------------------------------|--------------|---------------------------|----------------|-------------|-----|-------------------------------------|-------------------------------|---------------------------|
| Feehan et al. [38] | USA (Region of the Americas) | Individuals in New Orleans | Random | May, 2020 | CLIA | White (1607) Black (828) Asian (130) Native American (14) Multiracial /other (58) Hispanic (293) | 38.2% Mean 50.6 | | | | 2640 | 181 |
| Havers et al. [39] | USA (Region of the Americas) | Individuals in 10 Sites in the United States | Random | March–May, 2020 | ELISA |Highest % ≥ 65 5802 | | | | | 16,025 | 515 |
| McLaughlin et al. [75] | USA (Region of the Americas) | Individuals in a Ski Resort Community, Blaine County, Idaho, US | Random | May, 2020 | CLIA | Hispanic or Latino 59 Non-Hispanic or Latino 735 | 438 | | | | 917 | 208 |
| Menachemi et al. [76] | USA (Region of the Americas) | Individuals in Indiana | Random | April, 2020 | CLIA | White 33.73 (92) Nonwhite 281 (8) | 1,656 (40) | | | | 3658 | 246 |
| Ng et al. [77] | USA (Region of the Americas) | In donor and patient blood from the 2 San Francisco Bay Area | Random | March, 2020 | CLIA | | | | | | 387 | 1 |
Table 1 (continued)

| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender Male | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|---------------------------|---------------|-------------|-----|-------------------------------------|-------------------------------|--------------------------|
| Rosenberg et al. [25] | USA (Region of the Americas) | Among a 15,101 patron convenience sample at 99 grocery stores in 26 counties throughout NYS | Random | April, 2020 | MIA | Hispanic or Latino 17.4  NH-White 58.0  NH-Black/African American 13.9  NH-Asian 8.6  Multiracial/Other 2.1 | 47.6% | Highest % 55-36.1% | 15,101 | 1887 |  |
| Sood et al. [26] | USA (Region of the Americas) | Among adults in Los Angeles County, California | Random | April, 2020 | LFIA | Hispanic 190  White (non-Hispanic) 497  Black (non-Hispanic) 72  Other 104 | 347 | Highest % 35-54 475 | 863 | 35 |  |
Table 1 (continued)

| Authors (years) (R) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|---------------------|----------------------|------------------|----------------------------------------|--------------|---------------------------|---------------|--------|----|--------------------------------------|-------------------------------|---------------------------|
| Akinbami et al. [78] | USA (Region of the Americas) | Among healthcare, first response, and public safety personnel, Detroit metropolitan area, Michigan | Non-random | May–June 2020 | ELISA | No | % Seropositive | No | % Seropositive | Highest % | 18–24 | 45–59 |
|                     |                      |                  |                                        |              |              | Non-Hispanic White 12,858 | 6.0 | 5,146 (31.4) | 6.7 | 45–59 | 322 (31.9) | 18–24 | 7.9 |
|                     |                      |                  |                                        |              |              | Non-Hispanic Black 1,200 | 16.3 |                  |     |       |                    |       |   |
|                     |                      |                  |                                        |              |              | Non-Hispanic Asian 1,097 | 7.3 |                  |     |       |                    |       |   |
|                     |                      |                  |                                        |              |              | Hispanic 440 | 6.8 |                  |     |       |                    |       |   |
|                     |                      |                  |                                        |              |              | Other‡ 404 | 7.2 |                  |     |       |                    |       |   |
|                     |                      |                  |                                        |              |              | Declined to answer 398 | 7.0 |                  |     |       |                    |       |   |
| Berardis et al. [79] | Belgium (European Region) | In a Belgian cohort of patients with cystic fibrosis | Non-random | April–May 2020 | CLIA | 76 | Mean | 24.9 |                      | 149 | 4 (2.7%) |
| Borges et al. [80] | Brazil (Region of the Americas) | In an asymptomatic population in Sergipe | Random | May, 2020 | LFIA | 1469 (48.2%) | Mean | 39 |                      | 3046 | IgM 347 | IgG 218 |
| Borges et al. [81] | USA (Region of the Americas) | Among firefighters/paramedics of a US fire department | Non-random | April, 2020 | LFIA | White 1,54 (78.2) | Highest % | 41–50 | 67 (33.0) | 203 | 18 (8.9) |

Note: 
- CLIA: Chemiluminescent Immunoassay
- LFIA: Latex Agglutination Immunoassay
- ELISA: Enzyme-Linked Immunoabsorbent Assay
- IgM: Immunoglobulin M
- IgG: Immunoglobulin G
Table 1 (continued)

| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|---------------------------|---------------|--------|----|-------------------------------------|-------------------------------|-----------------------------|
| Clarke et al. [12] | United Kingdom (European Region) | In hemodialysis patients | Non-random | April–May, 2020 | CLIA | + (129) – (227) | Black 18 | White 29 | Indo-Asian 94 | Other 44 | Mean 46.5 | 356 | 129 |
| De Carlo et al. [82] | Italy (European Region) | In healthcare professionals of a Southern Italy hospital | Non-random | March–May, 2020 | CLIA | | | | | | | 3242 | 62 |
| Dingens et al. [83] | USA (Region of the Americas) | Among children visiting a hospital during the initial Seattle outbreak | Non-random | March–April, 2020 | ELISA | | | | | | | 1076 | 10 |
| Flannery et al. [84] | USA (Region of the Americas) | Among parturient women in Philadelphia | Non-random | April–June, 2020 | ELISA | Black/Non-Hispanic 537 | White/Non-Hispanic 447 | Hispanic/Latino 123 | Asian 106 | Other/Unknown 78 | 0 | Median 31 | 1293 | 80 |
| Halatoko et al. [85] | Togo (African Region) | Among high-risk populations in Lome’ (Togo) | Random | April–May, 2020 | ELISA | | | | | | | 955 | 9 |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|---------------------------|---------------|--------|-----|--------------------------------------|-------------------------------|--------------------------|
| Hunter et al. [86] | USA (Region of the Americas) | Among healthcare workers with differing levels of coronavirus disease 2019 (Covid-19) patient exposure | Random | April–May, 2020 | CLIA | | 30% | Mean 42.8 | | 734 | 12 |
| Khan et al. [87] | India (South-East Asia Region) | Hospital visitors across District Srinagar | Non-random | July, 2020 | CLIA | | 1463 | Highest % 30–49 1424 | | 2906 | 111 |
| Kobashi et al. [88] | Japan (Western Pacific Region) | Healthcare workers | Non-random | May, 2020 | CLIA | | 154 | 24.18% | Median 44 | 637 | IgM 2 | IgG 6 |
| Lastrucci et al. [89] | Italy (European Region) | In different essential activities during the general lock-down phase in the province of Prato (Tuscany, Italy) | Random | May, 2020 | ELISA | | 1532 | (32.9%) | Median 49 | 4656 | 138 (3.0%) |
| Mahajan et al. [90] | USA (Region of the Americas) | Among Adults Living in Connecticut | Random | June, 2020 | ELISA | Hispanic 49 | 244 | 47% | Mean 50.1 | 567 | 23 (4.1%) |
| Non-Hispanic White 470 | Non-Hispanic Black 37 | Non-Hispanic Asian 9 | Non-Hispanic Other 5 |
| Mansour et al. [91] | USA (Region of the Americas) | Among Healthcare Workers at a Tertiary Academic Hospital in New York City | Non-random | March–April, 2020 | ELISA | | 111 | (5.4%) | Mean 38 | 285 | 93 |
| Matern et al. [92] | France (European Region) | Circulation of SARS-CoV-2 in a maternity ward in an area that has been significantly affected | Non-random | May, 2020 | CLIA | | 0 | | Mean 33 | 249 | 20 |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|----------------------|------------------|----------------------------------------|--------------|--------------------------|---------------|--------|----|-----------------------------------|-------------------------------|-----------------------------|
| McDade et al. [93] USA (Region of the Americas) | among household members of essential workers | Random | April–May, 2020 | ELISA | 105 | Mean 37 | 232 | 30 |
| Naranbhai et al. [94] USA (Region of the Americas) | Chelsea residents, aged ≥ 18 years, with no current symptoms and no history of a positive SARS-CoV-2 PCR test | Non-random | April, 2020 | ELISA | 120 (60%) | Median 46 | 200 | 63 |
| Oliveira et al. [95] Brazil (Region of the Americas) | In outpatients of a large public university hospital in Sao Paulo, Brazil | Random | June–August, 2020 | ECLIA | 156 (35.5) | Highest % 40–59 | 439 | 61 |
| Pollán et al. [96] Spain (European Region) | Spanish population | Random | April–May, 2020 | CLIA | 29 349 | Highest % 50–64 13 906 | 61 075 | 3054 (5%) |
| Psichogiou et al. [97] Greece (European Region) | among health care workers in a country with low burden of Covid-19 | Random | April–May, 2020 | LFIA | 453 | Highest % 35–54 922 | 14 95 | 15 |
| Racine-Brazostek et al. [98] USA (Region of the Americas) | in New York City Health Care Workers | Random | April–May, 2020 | ELISA | 834 | Mean 37 | 2 274 | 805 |
| Shields et al. [99] United Kingdom (European Region) | in healthcare workers | Random | April, 2020 | ELISA | 128 (24.8%) | Median 42 | 516 | 126 |
| Sood et al. [100] USA (Region of the Americas) | Among adults in Los Angeles County, California | Random | April, 2020 | LFIA | Hispanic 190 | Highest % 35–54 4 75 | 863 | 100 |
| Authors (years) (R) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender Male | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|--------------------|---------------------|------------------|----------------------------------------|--------------|--------------------------|---------------|-------------|-----|--------------------------------------|----------------------------------|--------------------------|
| Tang et al. [101]  | China (Western Pacific Region) | In hemodialysis centers | Non-random | December, 2019- March, 2020 | ELISA | 619 (60.3%) | Mean 60.3 | 1027 | 47 |
| Younas et al. [21] | Pakistan (Eastern Mediterranean Region) | Among healthy blood donors in Karachi, Pakistan | Random | June,2020 | ECLIA | 380 | Mean 30.6 | 380 | 128 (33.6%) |
| Anna et al. [24]   | France (European Region) | Individuals in Paris | Non-random | March–April 2020 | ELISA | 418 | 22.6% | Mean 38 | 1847 | 183 |
| Banjar et al. [102] | Saudi Arabia (Eastern Mediterranean Region) | Among blood donors in the early months of the pandemic in Saudi Arabia | Random | May,2020 | ECLIA | 796 | Mean 33.3 | 837 | 12 |
| Coatsworth et al. [103] | Australia (Western Pacific Region) | In elective surgical patients in Australia | Non-random | June–July 2020 | ELISA | 1479 | 48.7% | Mean 54 | 3037 | 15 |
| Ebinger et al. [104] | USA (Region of the Americas) | In healthcare workers | Random | May,2020 | CLIA | 1876 (32) | 73 (3.4) | Mean 41.6 | 6062 | 212 |
| Kantele et al. [105] | Finland (European Region) | Among healthcare workers at Helsinki University Hospital, Finland | Non-random | March–April 2020 | ELISA | 187 | 17.3% | Median 38 | 1095 | 33 |
Table 1 (continued)

| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|----------------------|------------------|----------------------------------------|--------------|--------------------------|---------------|--------|----|--------------------------------------|-------------------------------|--------------------------|
| Ladoire et al. [106] | France (European Region) | Among the staff and patients of a French cancer center after first lockdown | Non-random | May–June 2020 | ECLIA | Employees (+) 139 (21.4%) | Mean (+) 35.3 | 38.6 | 663 | 12 |
| Laursen et al. [107] | Sweden-Denmark (European Region) | Among Danish and Swedish Falck Emergency and Non-Emergency Healthcare Workers | Random | June–August 2020 | LFIA | Swedish 1248 | Highest % 40–60 | 1732 (52.9) | 3272 | 159 (4.9%) |
| Lombardi et al. [108] | Italy (European Region) | Among healthcare workers of a large university hospital in Milan, Lombardy, Italy | Random | April–June 2020 | CLIA | 1232 | Mean 44.8 | 4055 | 309 |
| Moncunill et al. [109] | Spain (European Region) | Among healthcare workers in a Spanish hospital after 3 months of follow-up | Random | April–May 2020 | ELISA | 206 | Mean 42 | 565 | 82 |
| Pan et al. [110] | Taiwan (Western Pacific Region) | Among healthcare workers in a tertiary care hospital in Taiwan | Random | July–August 2020 | ELISA | 70 | Mean 36.3 | 194 | 64 |
| Pereckait et al. [111] | Lithuania (European Region) | In healthcare workers of Kaunas Hospitals | Random | June–September 2020 | LFIA | 63 | Mean 43.4 | 432 | 5 |
| McQuade et al. [112] | USA (Region of the Americas) | Among Outpatients in Virginia | Random | June–August, 2020 | ELISA | Hispanic 396 | Mean 48.8 | 4675 | 101 |
| Venugopal et al. [113] | USA (Region of the Americas) | Among health care workers in a New York City hospital | Random | March–May, 2020 | ELISA | Hispanic 132 (28%) | Highest % 20–39 | 230 | 478 | 130 |
| Authors (years) | Country/WHO Regions | Study population | Sampling methods (random or non-random) | Study period | Type of detection methods | Race/ethnicity | Gender | Age | Seropositive people (based on months) | No. of people screened (sample size) | Seropositive people (total) |
|----------------|---------------------|------------------|----------------------------------------|--------------|---------------------------|----------------|--------|-----|--------------------------------|-----------------------------|--------------------------|
| Malagón-Rojas et al [114] | Colombia (Region of the Americas) | Healthcare workers in Colombia | Random | September–November 2020 | CLIA | Afro-Colombian 216, White 995, Indigenous 112, Mestizo 2004, Raizal 19, Gipsy 6 | 788 | 36.45 ± 10.5 | 3296 | 1021 |
| Poustchi et al. [115] | Iran (Eastern Mediterranean Region) | High-risk occupational groups | Random | April 17 and June 2, 2020 | ELISA | 1795 | Highest % 30–39 | 494 |
| Poulikakos et al. [116] | England (European Region) | Healthcare workers in a tertiary center in North West | Random | May 2020 | ELISA | Black or BAME 55 (19.6%), did not declare ethnicity 25 (8.9%), DIPC 195 (69.4%) | 205 (73%) | 281 | 17 |
| Amendola et al. [117] | Italy (European Region) | Healthcare workers of the largest children hospital in Milan | Non-random | April 15, 2020 | ELISA | 108 | Median 44 | 663 | 34 |
| Brandstetter et al. [118] | Germany (European Region) | Hospital staff | Random | March 2020 | ELISA | 30 | Highest % 36–50 | 201 | 31 |
| Chibwana et al. [119] | Malawi (African Region) | Health Care Workers | Random | May 2020 to June 2020 | ELISA | 236 | Median 31 | 500 | 84 |
Table 2  Results of quality assessment based on JBI checklist

| Inclusion criteria | Detailed description of the population | Exposure (validity and reliability) | Condition | Identification of confounding factors | Deal with confounding factors | Outcome | Statistical analysis |
|--------------------|----------------------------------------|--------------------------------------|-----------|--------------------------------------|------------------------------|---------|---------------------|
| Herzog et al.      | Yes                                    | Yes                                  | Yes       | Unclear                              | Unclear                      | Yes     | Yes                 |
| Filho et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Silveira et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Torres et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Chang et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| To et al.          | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Liang et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Jerković et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Erikstrup et al.   | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Petersen et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Ward et al.        | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Gallian et al.     | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Grzelak et al.     | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Fischer et al.     | Yes                                    | No                                   | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Weis et al.        | Yes                                    | Unclear                              | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Bogogiannidou et al.| No                                     | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Merkely et al.     | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Shakiba et al.     | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Percivalle et al.  | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Valenti et al.     | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Fiore et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Doi et al.         | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Takita et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Takita et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Uyoga et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Song et al.        | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Kammon et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Snoeck et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Sam et al.         | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Pollán et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Lundkvist et al.   | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Stringhini et al.  | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Bendavid et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Biggs et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Bryan et al.       | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Dietrich et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Feehan et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Havers et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| McLaughlin et al.  | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Menachemi et al.   | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Ng et al.          | No                                     | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Rosenberg et al.   | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Sood et al.        | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Akinbami et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
| Berardis et al.    | Yes                                    | Yes                                  | Yes       | Yes                                  | Unclear                      | Yes     | Yes                 |
| Borges et al.      | Yes                                    | Yes                                  | Yes       | Yes                                  | Yes                          | Yes     | Yes                 |
### Table 2 (continued)

| Inclusion criteria | Detailed description of the population | Exposure (validity and reliability) | Condition | Identification of confounding factors | Deal with confounding factors | Outcome | Statistical analysis |
|--------------------|----------------------------------------|-------------------------------------|-----------|---------------------------------------|-------------------------------|---------|----------------------|
| Caban-Martinez et al. | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| Clarke et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| De Carlo et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Dingens et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Flannery et al. | Yes | Yes | Yes | Yes | Unclear | Yes | Yes | Yes |
| Halatoko et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Hunter et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Khan et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Kobashi et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Lastrucci et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mahajan et al. | Yes | Yes | Yes | Yes | Unclear | Yes | Yes | Yes |
| Mansour et al. | Yes | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| Mattern et al. | Yes | Yes | Yes | Yes | Yes | Unclear | No | Yes |
| McDade et al. | Yes | Yes | Yes | Yes | Yes | Yes | Unclear | Yes |
| Narainbhai et al. | Yes | Yes | Yes | Yes | Unclear | Yes | Yes | Yes |
| Oliveira et al. | Yes | Yes | Yes | Yes | Unclear | Yes | Yes | Yes |
| Psichogiou et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Racine-Brzostek et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No |
| Shields et al. | Yes | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| Sood et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Unclear |
| Tang et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Younas et al. | Yes | No | Yes | Yes | Yes | Yes | Unclear | Yes |
| Anna et al. | Unclear | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| Banjar et al. | Yes | Yes | Yes | Yes | Unclear | Unclear | Yes | Yes |
| Coatsworth et al. | Yes | Yes | Yes | Yes | Yes | Yes | Unclear | Yes |
| Ebinger et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Kantele et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Ladoire et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Laursen et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Unclear |
| Lombardi et al. | Yes | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| Moncunill et al. | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Pan et al. | Yes | Yes | Yes | Yes | Yes | Unclear | Yes | Unclear |
| Pereckait et al. | Yes | Yes | Yes | Yes | Unclear | Unclear | Yes | Unclear |
| McQuade et al. | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Venugopal et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Malagón-Rojas et al. | Yes | Yes | Yes | Yes | Yes | Unclear | Yes | Yes |
| Poustchi et al. | Yes | Yes | Unclear | Yes | Yes | Yes | Yes | Yes |
| Poulikakos et al. | Yes | Yes | Yes | No | Yes | No | Unclear | Yes |
| Amendola et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Brandstetter et al. | Yes | Yes | Yes | Yes | Unclear | Yes | Unclear | Yes |
| Chibwana et al. | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
and the results were analysed [16]. Cochrane Q and I2 tests were used to investigate the heterogeneity and variance between the studies selected for meta-analysis [17–20]. Funnel Plot and Egger test were used to evaluate the publication bias [19, 20]. Also, the meta-regression analysis and diagram were used to examine the association between important variables with the estimated pooled prevalence. Statistical analysis was performed using STATA 16.0.

**Results**

As a result of searching the electronic databases, 3413 studies were obtained, and after removing duplicates, 2507 studies remained. After eliminating studies conducted before 2019, 1926 titles remained for review. In the last stage, after reviewing titles, abstracts, and full texts and considering the inclusion and exclusion criteria, 88 studies were selected for inclusion in the study (Fig. 1).

All 88 studies entered at different time intervals examined the prevalence of positive tests in various communities (Table 1). In total, 414,773 serological tests were performed in all studies. Studies have been reviewed in different countries and were also divided according to WHO classifications. In total, studies have been conducted in 34 countries, with 26 in the United States, 7 in Italy, 5 in France, 4 in each country of Japan, the United Kingdom, Brazil, and China, 3 in each country of Spain, Germany, and Denmark, and 2 in each country of Belgium, Iran, Greece, and Sweden, and 1 in each one of the other countries. According to the WHO classification, there were four studies in the Eastern Mediterranean, 4 in Africa, 31 in America, 35 in Europe, and 12 in Western Pacific.

The quality assessment checklist of the observational studies showed that most of these studies had a good quality. Except for a few of the studies had unknown parts in the checklist (Table 2).

**Seropositive in Eastern Mediterranean population**

Four studies with a total sample size of 5298 cases determined the prevalence of SARS-CoV-2 in this area. The lowest correlation belonged to the study of Banjar et al. with a prevalence of 1% (95% CI 1 to 2%), and the highest prevalence belonged to the study of Younas et al. with a prevalence of 34% (95% CI 29 to 39%). After combining the results of these studies, the pooled estimate was equal to 15%, with a 95% confidence interval of 5 to 29% (Figs. 2 and 7). The highest value was in Pakistan with a prevalence of 24% (95% CI 19 to 39%), and the lowest was in Saudi Arabia with a prevalence of 1% (95% CI 1 to 2%) (Table 3).

**Seropositive in Africa population**

Four studies with a total sample size of 5298 cases determined the prevalence of SARS-CoV-2 positive serological tests in this area. The lowest correlation belonged to the study of Halatoko et al. with a prevalence of 1% (95% CI 1 to 2%), and the highest prevalence belonged to the study of Younas et al. with a prevalence of 34% (95% CI 29 to 39%). After combining the results of these studies, the pooled estimate was equal to 15%, with a 95% confidence interval of 5 to 29% (Figs. 2 and 7). The highest value was in Pakistan with a prevalence of 24% (95% CI 19 to 39%), and the lowest was in Saudi Arabia with a prevalence of 1% (95% CI 1 to 2%) (Table 3).
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(Figs. 3 and 7). Also, among the countries in this region, the highest value was related to Malawi with a prevalence of 17% (95% CI 14 to 20%) and the lowest to Togo with a prevalence of 1% (95% CI 0 to 2%) (Table 3).

Seropositive in America population
Thirty-one studies determined the prevalence of SARS-CoV-2 positive serological tests in this area, with the lowest correlation belonging to the study of Ng et al. with a prevalence of 0% (95% CI 0 to 1%) and also the study of Silveira et al. with a prevalence of 0% (95% CI 0 to 1%). The highest prevalence belonged to the study of Racine-Brzostek et al., with a prevalence of 35% (95% CI 33 to 37%). After combining the results of these studies, the pooled estimate was equal to 8%, with a 95% confidence interval of 6 to 10% (Figs. 4 and 7). According to the analysis, among the countries in this region, the highest value was related to Colombia with a prevalence of 29% (95% CI 23 to 31%) and the lowest to Brazil with a prevalence of 7% (95% CI 2 to 12%) (Table 3).

In the subgroup analysis related to this area, the prevalence was also examined based on the population type (healthy and unhealthy), the diagnostic test type (ELISA–CLISA–LFIA), the sampling type (random and non-random), time (months after pandemic), the perspective (local–regional–national), and the type of the study (cohort–cross-sectional). According to the classification based on the type of population, the results showed that the serological test’s positivity was 5% in healthy people (95% CI 4 to 6%). In addition, the evaluation results differed according to the test type, and the prevalence of positive tests was 12% for ELISA (95% CI 10 to 15%), 6% for CLISA (95% CI 4 to 8), and 6% for LFIA (95% CI 4 to 9%). The results showed that the highest prevalence occurred in the diagnostic subgroup of ELISA. Also, depending on the type of sampling, in randomized studies, the prevalence was 9% (95% CI 7 to 11%), and in non-randomized studies, the prevalence was 10% (95% CI 7 to 13%). This indicated a higher prevalence in the non-randomized group. Based on the months after pandemic, the prevalence were 7% for 4 month (95% CI 3 to 12%), 8% for 5 month (95% CI 4 to 13%), 9% for 6 month (95% CI 6 to 14%), and 11% for 7 month (95% CI 0 to 32%). Over time, this prevalence increased. Prevalence based on perspective was 12% for local (95% CI 6 to 19%), 6% for regional (95% CI 4 to 10%), and 3% for national (95% CI 4 to 10%), which was higher in local studies. Also, prevalence was 7% for cohort (95% CI 2 to 14%), and 9% for cross-sectional (95% CI 6 to 12%). Prevalence was higher in cross-sectional studies (Table 4).

Seropositive in European population
In addition, 35 studies determined the prevalence of SARS-CoV-2 positive serological tests in this area with the lowest correlation belonging to the study of Fischer et al. with a prevalence of 01% (95% CI 01 to 01%) and also the study of Merkely et al. with a prevalence of 01%
The highest correlation belonged to the study of Clarke et al., with a prevalence of 36% (95% CI 31 to 41%). After combining the results of these studies, the pooled estimate was equal to 5% with a 95% confidence interval of 4 to 6% (Figs. 5 and 7). In addition, the highest value was related to the United Kingdom among the countries in this region, with a prevalence of 20% (95% CI 4 to 45%). The lowest was associated with Greece, with a prevalence of 1% (95% CI 0 to 2%) (Table 3).

In the subgroup analysis related to this area, the prevalence was also examined based on the population type (healthy and unhealthy), the diagnostic test type (ELISA–CLISA–LFIA–VN–ECLIA), and the sampling type (random and non-random), time (months after pandemic), the perspective (local–regional–national), and the type of the study (cohort–cross-sectional). The classification results by the population type showed the positivity of the serological test in the healthy and unhealthy populations at 5% (95% CI 4 to 6%) and 20% (95% CI 16 to 23%), respectively. Prevalence in the unhealthy population was higher. The results obtained based on the type of the diagnostic test were different, and the prevalence of positive tests was 6% for ELISA (95% CI 4 to 8%), 6% for CLISA (95% CI 3 to 9%), 4% for LFIA (95% CI 2 to 8%), 7% for VN (95% CI 5 to 8%), and 1% for ECLIA (95% CI 1 to 3%). The highest value was evaluated in VN type. Also, depending on the type of sampling, the prevalence in randomized studies was 5% (95% CI 4 to 6%), and in non-randomized studies, it was 6% (95% CI 3 to 8%). Prevalence was higher in non-randomized studies (Table 4). For the months after pandemic, the prevalence were 23% for 2 month (95% CI 19 to 28%), 5% for 3 month (95% CI 4 to 7%), 4% for 4 month (95% CI 2 to 7%), 6% for 5 month (95% CI 5 to 8%), 3% for 6 month (95% CI 2 to 6%), and 5% for 7 month (95% CI 3 to 7%). The highest prevalence was in the 2 months after the pandemic. Prevalence based on perspective was 8% for local (95% CI 6 to 11%), 6% for regional (95% CI 3 to 8%), and 3% for national (95% CI 2 to 4%) indicating higher prevalence in local studies. Prevalence based on type of study was 5% for cohort (95% CI 2 to 8%), and 6% for cross-sectional (95% CI 5 to 7%). Prevalence was higher in cross-sectional studies (Table 4).

### Seropositive in Western Pacific population

Finally, 12 studies determined the prevalence of SARS-CoV-2 positive serological tests in this area, with the lowest correlation belonging to the study of Coatsworth et al. with a prevalence of 0% (95% CI 0 to 1%) and the highest correlation belonging to the study of Pan et al. with a prevalence of 33% (95% CI 27 to 40%). After combining the results of these studies, the pooled estimate was equal to 3%, with a 95% confidence interval of 2 to 4% (Figs. 6 and 7). Finally, among the countries in this region, the highest value was related to Taiwan with a prevalence of 33% (95% CI 23 to 40%), and the lowest was associated with Malaysia with a prevalence of 0% (95% CI 0 to 2%) (Table 3).

In the subgroup analysis related to this region, the prevalence was also examined based on the population type (healthy and unhealthy), the diagnostic test type
(ELISA–CLISA–LFIA–VN), and the sampling type (random and non-random). The classification results based on the population type showed that the serological test was positive in 3% of the healthy population (95% CI 2 to 5%) and 2% of the unhealthy population (95% CI 1 to 3%). It was higher in the healthy population than in the unhealthy one. The results obtained based on the type of diagnostic test were different. The prevalence of positive tests was 7% for ELISA (95% CI 3 to 10%), 1% for CLISA (95% CI 0 to 2%), 4% for LFIA (95% CI 3 to 5%) and 1% for VN (95% CI 0 to 2%). The highest value was observed in the ELISA group. Also, depending on the type of sampling, the prevalence was 4% in randomized studies (95% CI 2 to 5%), and in non-randomized studies, the prevalence was 2% (95% CI 0 to 4%). The prevalence in the randomized group was higher than that in the non-randomized one (Table 4).

**Meta-regression results**

In this part, we analyzed the changes in SARS-CoV-2 seroprevalence in different WHO regions and worldwide based on the year from 2020 to 2021. The result in America (B: −0.03, SE: 0.05, P: 0.469), Europe (B: −0.01, SE: 0.02, P: 0.401), Western Pacific (B: −0.01, SE: 0.01, P: 0.430), Eastern Mediterranean (B: −0.19, SE: 0.08, P: 0.033) and around the World (B: −0.03, SE: 0.02, P: 0.122) was decreasing which in Western Pacific and World was significant. However, the result in Africa (B: 0.01, SE: 0.02, P: 0.854) was increased (Fig. 8).
Table 4 The subgroup analysis related to region, the prevalence was examined based on the population type (healthy and unhealthy), the diagnostic test type (ELISA–CLISA–LFIA–VN), and the sampling type (random and non-random)

| Regions        | Variables         | Pooled prevalence (95% CI) | Heterogeneity assessment |
|----------------|-------------------|-----------------------------|--------------------------|
|                |                   |                             | I square | P heterogeneity |     |
| Western Pacific| Study population  | Healthy                     | 3% (2–5%) | 90.20% | 0.000 |
|                |                   | Un-healthy                  | 2% (1–3%) | 91.55% | 0.000 |
|                | Diagnostic methods| ELISA                       | 7% (3–10%) | 17.03% | 0.281 |
|                |                   | CLIA                        | 1% (0–2%) | 0.00% | 0.320 |
|                |                   | LFIA                        | 4% (3–5%) | 41.35% | 0.160 |
|                |                   | VN                          | 1% (0–2%) | 55.02% | 0.301 |
|                | Sampling methods  | Random                      | 4% (2–5%) | 89.65% | 0.000 |
|                |                   | Non-random                  | 2% (0–4%) | 84.23% | 0.000 |
|                | Time              | 2 months after pandemic     | 2% (1–3%) | 93.20% | 0.000 |
|                |                   | 4 months after pandemic     | 3% (2–5%) | –     | –     |
|                |                   | 5 months after pandemic     | 4% (3–5%) | –     | –     |
|                |                   | 6 months after pandemic     | 2% (1–3%) | –     | –     |
|                |                   | 7 months after pandemic     | 1% (1–2%) | –     | –     |
|                |                   | 8 months after pandemic     | 5% (4–6%) | –     | –     |
|                | Perspective       | Local                       | 4% (2–6%) | 91.05% | 0.000 |
|                |                   | Regional                    | 3% (1–5%) | 89.04% | 0.000 |
|                |                   | National                    | –     | –     | –     |
|                | Type of study     | Cohort                      | 2% (1–3%) | 88.08% | 0.000 |
|                |                   | Cross-sectional             | 4% (2–6%) | 91.90% | 0.000 |
| European       | Study population  | Healthy                     | 5% (4–6%) | 92.15% | 0.000 |
|                |                   | Un-healthy                  | 20% (16–23%) | 89.22% | 0.000 |
|                | Diagnostic methods| ELISA                       | 6% (4–8%) | 78.65% | 0.030 |
|                |                   | CLIA                        | 6% (3–9%) | 79.99% | 0.001 |
|                |                   | LFIA                        | 4% (2–8%) | 90.36% | 0.000 |
|                |                   | VN                          | 7% (5–8%) | 77.00% | 0.000 |
|                |                   | ECLIAs                      | 1% (1–3%) | –     | –     |
|                | Sampling methods  | Random                      | 5% (4–6%) | 97.68% | 0.000 |
|                |                   | Non-random                  | 6% (3–8%) | 90.22% | 0.000 |
|                | Time              | 2 months after pandemic     | 23% (19–28%) | 88.17% | 0.000 |
|                |                   | 3 months after pandemic     | 5% (4–7%) | 89.06% | 0.000 |
|                |                   | 4 months after pandemic     | 4% (2–7%) | 92.54% | 0.000 |
|                |                   | 5 months after pandemic     | 6% (5–8%) | 84.28% | 0.000 |
|                |                   | 6 months after pandemic     | 3% (2–6%) | 98.90% | 0.000 |
|                |                   | 7 months after pandemic     | 5% (3–7%) | 87.09% | 0.000 |
|                | Perspective       | Local                       | 8% (6–11%) | 89.00% | 0.000 |
|                |                   | Regional                    | 6% (3–8%) | 88.89% | 0.000 |
|                |                   | National                    | 3% (2–4%) | 83.49% | 0.000 |
|                | Type of study     | Cohort                      | 5% (2–8%) | 99.90% | 0.000 |
|                |                   | Cross-sectional             | 6% (5–7%) | 98.56% | 0.000 |
Due to the current Covid-19 pandemic, the prevalence and incidence of this disease are increasing worldwide. Because antibodies are produced in response to many pathogens, including Covid-19, and have a higher advantage than other diagnostic methods in determining the serology prevalence, here we have globally collected verified data (by September 2020) to contribute to a comprehensive understanding of the current pandemic by conducting a comprehensive review of the prevalence of Covid-19 serology in different populations and geographical areas. In this meta-analysis, the cumulative prevalence was calculated at 414,773 based on the studied research, and 25,065 people in the world were infected with Covid-19 by the date of this study.

The results obtained based on the study region showed that among the six regions of the WHO, Eastern Mediterranean and Western Pacific had the highest (15%) and lowest (3%) prevalence, respectively. The largest sample size and number of studies were related to the European Region, accompanied by other development characteristics in this region. It is also impossible to accurately assess the Covid-19 prevalence based on just one study at the local level. Still, one can imagine the general situation from these few studies, especially globally. Although the exact protective effect of antibodies against mutant variants has not been determined so far [21], it can be said that the differences observed in seroprevalence are probably related to differences in the disease transmission status in the community due to behavioral differences, the public health status, local resources, and environmental issues. Of course, there are other issues, such as altitude and climatic differences, and the relevant evidence is not yet complete [22, 23]. Differences in the volume, time, single approach, sampling method, missing samples, sample size, selection bias, greater participation of symptomatic individuals, the inclusion of minority populations, lack of validity and reliability of questionnaires in determining symptoms, accuracy of diagnostic kits, rate of decrease in the antibody titer, possible reinfection, the persistence of the virus in a large population of the society, and diversity of geographical and demographic characteristics (age, sex, race, ethnicity, etc.) were among the limiting factors in most studies [24–26].

In the present study, the lowest Covid-19 seroprevalence was in Western Pacific and African countries, followed by European and American ones, and was slightly higher in the Eastern Mediterranean. However, within each of the World Health Organization's geographical areas, there were significant differences. For example, the

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Table 4 (continued)

| Regions | Variables | Pooled prevalence (95% CI) | Heterogeneity assessment |
|---------|-----------|-----------------------------|--------------------------|
|         |           |                             | I square | P heterogeneity |
| America | Study population | Healthy | 9% (8–12%) | 92.19% | 0.000 |
|         |           | Un-healthy | – | – | – |
|         | Diagnostic methods | ELISA | 12% (10–15%) | 79.00% | 0.001 |
|         |           | CLIA | 6% (4–8%) | 81.54% | 0.001 |
|         |           | LFIA | 6% (4–9%) | 88.99% | 0.000 |
|         |           | VN | – | – | – |
|         | Sampling methods | Random | 9% (7–11%) | 97.22% | 0.000 |
|         |           | Non-random | 10% (7–13%) | 98.48% | 0.000 |
|         | Time | 4 months after pandemic | 7% (3–12%) | 89.22% | 0.000 |
|         |           | 5 months after pandemic | 8% (5–13%) | 80.29% | 0.000 |
|         |           | 6 months after pandemic | 9% (6–14%) | 93.00% | 0.000 |
|         |           | 7 months after pandemic | 11% (0–32%) | 92.33% | 0.000 |
|         | Perspective | Local | 12% (6–19%) | 99.52% | 0.000 |
|         |           | Regional | 6% (4–10%) | 92.54% | 0.000 |
|         |           | National | 3% (4–10%) | – | – |
|         | Type of study | Cohort | 7% (2–14%) | 79.90% | 0.000 |
|         |           | Cross-sectional | 9% (6–12%) | 77.56% | 0.000 |
estimated prevalence in Taiwan (33%) was much higher than that of other Western Pacific countries. The same difference existed in Europe, so the United Kingdom, with an estimated prevalence of 20%, was significantly different from its neighbors. In contrast, the differences in the Americas and Africa were relatively small, and the Covid-19 seroprevalence was moderate in these regions. Finally, in the Eastern Mediterranean region, Covid-19 seroprevalence was relatively high in Iran and Pakistan, except in Saudi Arabia. Similar studies that have mainly classified the prevalence based on countries’ income reported that in some cases, middle-income countries and, in other instances, high-income countries had reported a higher prevalence [27, 28]. So, we could not find a precise correlation between the income level of countries and the Covid-19 seroprevalence, which may be due to differences in the time of epidemic changes in these countries, sampling and laboratory methods, disease control policies, and vaccination in different populations.

Studies used different serological tests. Due to the many reasons presented for the difference in Covid-19 seroprevalence in additional studies and populations, it was impossible to precisely determine the effect of the test type on this rate. Various studies showed that the type of used antigen, the number of passed days since the onset of the patient’s initial symptoms, and the performance of the serological test itself affected the sensitivity
and specificity of various tests [29–31]. The reported sensitivity for different tests was from 66 to 97%, while the specificity of all tests was reported to be higher than 95% [32, 33].

Different demographic subgroups such as healthy and unhealthy individuals and the randomized and non-randomized sampling, in general, can affect the difference in seroprevalence. As stated in the present study, studies reported lower and higher seroprevalence in different geographic perspectives and time from the beginning of the pandemic areas in each category. For example, in the Western Pacific countries, the seroprevalence of healthy populations was higher than that of unhealthy ones. In cases with the random sampling method, it was more than the non-random one. Also, in our study, the seroprevalence increased from local to national perspectives, respectively, due to the impact of more facilities, effective health policies, and easier access to health care services at the national level. In general, the samples taken in our study were in the time period from 2 January to 21 September 2020. In this period, clinical management of the disease was based on symptomatic therapies. Still, non-pharmaceutical interventions (NPIs) such as physical distance in all settings, hand hygiene and use of protective equipment self and large-scale isolation, and closure of borders, schools, and workplaces play a critical role in preventing and controlling disease transmission. Therefore, problems with infrastructure, imports of some drugs, and strategies such as quarantine, proper promotion, or non-observance of the mentioned factors can change the prevalence of the disease months from the beginning of the pandemic. For example, the prevalence peaked in Western Pacific and European countries in April 2020.

Also, specific mutations in the SARS-CoV-2 genome over time impacted diagnostics, transmissibility, and treatment. And the first variant (alpha) was identified in late 2020, so the obtained seroprevalence pattern cannot be justified by Covid-19 variants [34, 35]. Hence, there were no effective and available vaccines or drugs against Covid-19 in our study period. The first public vaccine was given to a 91-year-old woman in The UK named Margaret Keenan on 8th December 2020 [36]; the results of the current meta-analysis may be less justified by vaccination and viral variants, so conducting such seroprevalence studies would need to be done again carefully.

In the meta-regression performed based on the observed changes in Covid-19 seroprevalence over time,
it was found that other countries showed a downward trend despite our expectation of this increase over time, except in the subgroup of African countries in Covid-19 seroprevalence. This may be due to differences in sampling times in different countries due to the peak of the disease and changes in prevention systems in these countries on the one hand and the instability of Covid-19 specific antigens over time on the other hand.

One of the strengths of this study was the global review of Covid-19 seroprevalence studies. Also, in this research, studies were aggregated by different regions of the World Health Organization, while in similar studies, classification was more based on the income level of countries [27, 28]. Also, in this study, changes in the seroprevalence time of populations were presented first. On the other hand, one of the weaknesses of the research was the lack of a sample study from all people and countries of the world to better estimate global seroprevalence. Also, some countries had only one study on the existing cases, and others reported several ones. Indeed, the prevalence of Covid-19 varies in different subgroups and varies according to epidemic changes and prevention policies. Therefore, with a small number of studies, the demographic and temporal generalizability of the findings is problematic. Also, different sampling methods, tests, different times passed from the onset of symptoms in different people, and other antigens make it challenging to interpret the findings uniformly. The probability of underestimating seroprevalence in the world is high. If the prevalence is higher with confirmed cases, a lower death rate can be found in all cases of infection [26]. According to the findings of the studies, the highest prevalence was seen in ethnic and racial minorities such as Blacks and South Asians than Whites. Factors related to this finding include various determinants of health inequality, including discrimination, access to health care, the employment status and its related factors, financial and educational gaps, the housing status and the number of household members, and in general, occupational, social, and environmental variables [37–39].
Conclusion
The present research performed on 88 studies showed that the seroprevalence of Covid-19 has been between 3 and 15% worldwide, and even considering the low estimate of this rate and the increasing vaccination in the world, a large number of people are still susceptible to Covid-19. Countries need to implement prevention policies with greater sensitivity and follow-up, especially those with low Covid-19 serology prevalence and vaccination coverage.
Abbreviations
WHO: World Health Organization; SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2; RT-PCR: Real-time reverse transcription-polymerase chain reaction; PCR: Polymerase chain reaction; Nab: Neutralizing antibodies; LFIA: Lateral flow immunoassays; ELISA: Enzyme-linked immunosorbent assay; FIA: Fluorescence immunoassays; CLIA: Chemiluminescence assays; PSV: Pseudo-virus neutralization assay; VN: Virus neutralization assay; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses; BJI: Joanna Briggs Institute; CI: Confidence interval; CINAHL: Cumulative Index to Nursing and Allied Health Literature; EMBASE: Excerpta Medica database.

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Author contributions
AA conceptualized the idea for this review, formulated the review question and objectives, assisted with the development of the final search strategy, contributed to the data analysis/interpretation, and writing the manuscript. YM, MA, and AM contributed to the conceptualization of the final review question, formulation of the review objectives, data analysis/interpretation, and writing the manuscript. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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