Diagnostic Utility of Antigen Detection Rapid Diagnostic Tests for Covid-19: A Systematic Review and Meta-Analysis

Mina Ebrahimi¹, Narges Nazari Harmooshi², Fakher Rahim¹*

¹. Thalassemia and Hemoglobinopathy Research Centre, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.
². Epidemiology, Deputy of Health, Health Centre, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

*Corresponding author: Thalassemia and Hemoglobinopathy Research Centre, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. Bioinfo2003@gmail.com.

Abstract

Background: Early detection of coronavirus disease (COVID-19) infection to improve disease management, becomes the greatest challenge. Despite high sensitivity of RT-PCR, not only it was reported that 20-67% of infected patients have false negative results. Rapid diagnostic tests (RDTs) are widely used as a point-of-care test for SARS-CoV-2 detection in both pharyngeal and blood specimens. To be less time-consuming, not seem so costly, and requiring no special training make it more favorable, but the low sensitivity is the main limitation. Several reports indicated rapid test of blood and pharyngeal samples has the same sensitivity as the RT-PCR, but some reports have lower sensitivity especial in asymptomatic patients. Methods: In the present survey, we investigate the eligible studies for sensitivity and specificity of rapid tests and explore the factors that influence the result to help better diagnose COVID-19 infection. 20 studies met the inclusion criteria, which impose 33 different tests. Results: Our findings showed, type of sample, type of assay, time of sampling, and load of virus influence on sensitivity of RDTs. Conclusion: This research extends our knowledge of how to improve the sensitivity of RDTs to better diagnose of infected patients to address the controlling COVID-19 pandemic.

Keywords: RDTs, rapid diagnostic test, RT-PCR, COVID-19, sensitivity, specificity.
Introduction

Early detection of coronavirus disease (COVID-19) infection to improve disease management, becomes the greatest challenge. Real-time PCR (RT-PCR) was introduced as a gold standard test in the laboratory. Despite high sensitivity of RT-PCR, not only it was reported that 20-67% of infected patients have false negative results, but also RT-PCR cannot differentiate between infectious and non-infectious SARS-CoV-2 particles (1,2). Rapid diagnostic tests (RDTs) are widely used as a point-of-care test for SARS-CoV-2 detection in both pharyngeal and blood specimens. To be less time-consuming, not seem so costly, and requiring no special training make it more favorable, but the low sensitivity is the main limitation. Additional to the rapid antigen (Ag) test, the rapid antibody (Ab) test was considered as a timely point-of-care test to detect IgG and IgM Abs in blood, plasma, and serum of patient with COVID-19 (3,4). In a recent study Ricks et al. analyzed the health system cost and health impact of using RDTs among hospitalization and mildly symptomatic patient with COVID-19, and report that despite the low sensitivity of RDTs compare with RT-PCR, is accompanied with "Ag-RDTs have the potential to be simultaneously more impactful with a lower cost per death and infectious person-days averted" (5).

Several reports indicated rapid test of blood and pharyngeal samples has the same sensitivity as the RT-PCR, but some reports have lower sensitivity especial in asymptomatic patients (6–10). These controversial results may be due to the different sample types or examined in different infection stages. In the present systematic review, we attempt to assess the diagnostic utility of antigen detection rapid diagnostic tests for covid-19 versus RT-PCR in a different type of samples and different stages of infection determine the usability of rapid tests in best time and sample.

Materials and Methods

This review was performed following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) and MOOSE (Meta-analyses Of Observational Studies in Epidemiology) guidelines (11,12).

Search Strategy

To evaluate the usability of rapid tests compare with RT-PCR, we systematically searched the electronic database, including Scopus, Medline/PubMed, EMBASE, Web of sciences
(WOS), and Cochrane library using Mesh-standardized keywords: (((Rapid antigen detection test * OR RDT*) OR “Rapid Antigen Test”[Mesh] OR “point of care testing”) AND (“Real-time PCR”[Mesh] OR “RT-PCR” OR "Molecular diagnostic test” OR “RNA virus”) AND (“2019 nCoV”[tiab] OR 2019nCoV[tiab] OR "2019 novel coronavirus”[tiab] OR "COVID 19”[tiab] OR COVID19[tiab] OR "new coronavirus”[tiab] OR "novel coronavirus”[tiab] OR "novel coronavirus”[tiab] OR "SARS CoV-2”[tiab] OR (Wuhan[tiab] AND (coronavirus[tiab] OR "corona virus”[tiab]) OR "COVID-19”[Supplementary Concept] OR "severe acute respiratory syndrome coronavirus 2”[Supplementary Concept]])) until Jan 2021. There is no restriction for time and language, and the citation lists of selected articles were hand-searched for additional papers.

**Data extraction**

Two reviewers (ME and FR) independently screened titles and abstracts of all initially found articles. Information was extracted from selected studies, including the name of the author, country, sample size, mean age, rapid diagnostic kits, true positive, false positive, false negative, true negative results, sensitivity, and specificity. A third reviewer was consulted to resolve any disagreements between reviewers by discussion until consensus was reached.

**Eligible Criteria**

In order to understand the sensitivity and specificity of RDTs, studies that evaluated these parameters were selected. Inclusion criteria were considered as following: evaluation of the sensitivity and specificity of RDTs compare to the RT-PCR. All types of studies, including case/control, cohort, cross-sectional, and clinical trial studies, were included. Additionally, letter to editors which reported comprehensive data was included. Studies that evaluated seroprevalence, studies that investigated just cell culture assay, case reports, reviews, and studies reporting cases with incomplete information were excluded.

**Statistical Analysis**

Cochran Chi-square test and \( I^2 \) were used to assessing heterogeneity among studies. A fixed-effects model was used when \( I^2 < 50\% \), while in the case of \( I^2 > 50\% \), a random-effects model was selected. Fixed-model assumes that the population effect sizes are the same for all studies (13). In contrast, the random-effects model attempted to generalize
findings beyond the included studies by assuming that the selected studies are random samples from a larger population (14). To compare the sensitivity and specificity in RDTs compared with the RT-PCR, 95% confidence intervals (CI) were used. According to the heterogeneity test results, either Der Simonian’s and Laird’s random-effects method or Mantel-Haenszel’s fixed-effects method were used to estimate the overall sensitivity and specificity and 95% confidence intervals (15). Moreover, subgroup analysis was implemented based on the type of specimen (nasopharyngeal swab, throat washing and bronchoalveolar fluids, and Nasal sample), and symptomatic or asymptomatic patients as an important variable which may cause heterogeneity between different samples or influence of onset of symptoms. The Egger’s test was used to investigate small study effects due to potential publication bias (16,17). If there was statistical heterogeneity among the results, a further sensitivity analysis was conducted to determine the source of heterogeneity. After the significant clinical heterogeneity was excluded, the randomized effects model was used for meta-analysis. P < 0.05 was considered as statistical significance (2-sided). All data were analyzed using STAT 16 (STATA Corporation, College Station, Texas).

Result

Overall, 783 studies were initially collected. After removing duplicated studies, 580 studies have remained. During screening titles and abstracts, 165 studies were considered potentially eligible. Subsequently, in full-text screening, 295 studies were excluded (Figure 1). Finally, 20 studies met our inclusion criteria, which impose 33 different tests (including 26,056 patients, mean age range from 20.5 to 53.14 years). Eleven studies (55%) evaluated nasopharyngeal swabs (5,6,8,12–20). Three of included studies investigated various types of samples with just one assay (18,27,28), whereas other two articles examined one type of sample with different assays to comparing sensitivity and specificity (7,9). A single study performed a similar series of experiments but for rapid Abs tests with finger-stick whole-blood (10), whereas other two studies were used the same rapid Abs tests from patient’s serum (29,30). Characteristics of diagnostic values of included studies are shown in Table 1. Forest plots illustrating sensitivity and specificity for each analysis are seen in Figure 2. The results of Cochrane Q and $I^2$ statistics showed significant heterogeneity in sensitivity and specificity, so estimations of sensitivity and specificity were obtained using a random effect model. In
Further analysis, data were analyzed based on the type of sample and symptomatic or asymptomatic patients Table S1-S5 and Figure S1-S5. Summary ROC curves constructed for all assays based on Monte Carlo simulations are shown in Figure 3. It did not apply to assessing the false results, because 7 studies (35%) did not focus on false results (7,9,18,22,28,30–32). Some of the current kinds of literature which focused on Ab rapid tests were excluded due to reporting the results as the separate sensitivity for IgG and IgM or analyzed data based on onset of symptoms (3,33).

Discussion

Following broad speared spectrum of COVID-19 infection, identified infected patients and carriers as soon as possible help to better control pandemic. In this line, the RDTs and rapid Abs test for detecting patients were introduced by WHO in a short time. A large and growing body of literature has investigated these tests' usability based on their sensitivity and specificity compared to the RT-PCR. Inconsistency in reported results has heightened the need for a comprehensive search to achieving a reliable finding. In this regard, in the present survey, we investigate the eligible studies for sensitivity and specificity of rapid tests and explore the factors that influence the result to help better diagnose COVID-19 infection.

One important factor that influences the sensitivity of RDTs is a type of sample. Studies that evaluated different types of samples revealed that nasal examination swabs and saliva specimens for RDTs are associated with lower sensitivity (27). Our results showed the most collected samples were nasopharyngeal swabs; in this line, it was shown examine nasopharyngeal swab, the sensitivity of RDTs results increases (9,38). After evaluating various specimens, Yamayoshi et al. found that soaking specimen directly to the lysing buffer can improve RDTs sensitivity (38).

Our analysis has shown the higher sensitivity observes in infected patients with lower Ct value by RT-PCR. In fact, in asymptomatic patients or patients with lower viral load, the sensitivity of RDTs decreases (6,8,39). In the subsequent analysis, Cerutti et al. examine the STANDARD Q COVID-19 Ags (R-Ag) among infected patients; they demonstrated that patients who were positive for R-Ag have higher viral load and lower Ct value are symptomatic, and this can be an explanation higher RDTs sensitivity in symptomatic subjects (19). In contrast, Pilarowski et al. reported asymptomatic subjects should not
rule out because regardless of symptoms, it can be possible asymptomatic patients have a viral load (40). In this regard, to the assessment of RDTs sensitivity, Eshghifar et al. used various concentration of heat-inactivated COVID-19 virus to assess a cut-off detection for RDTs; their findings showed, they could not determine a cut-off and reported RDTs to be positive just in patients with high viral load (28); whereas CK Mak et al. by using cell culture, the limiting of detection for RDTs reported 18.57 (18).

Additional to the RDTs, some writers compared the sensitivity of cell culture with RT-PCR for detecting COVID-19. Like the RDTs, the result showed that in cell culture with lowing viral load, the sensitivity reduces (8). This can be explained by the fact that specimens with low viral load or Ct value >30 do not cultured, suggesting low infectivity of virus (41).

Conducting RDTs with various assays is a serious discussion that can cause emerging different sensitivity. A study that set out to determine sensitivity of various assay for RDTs found different results for positive controls in different assays; which could offer the current methods detect different Ags and subsequently influence test accuracy (32).

The possible interference of time of testing cannot be ruled out. Some researchers revealed that testing less than 5 days from the onset of symptoms increases sensitivity (8,9,22,28). It is inconsistent with previous reports that a load of infectious virus decreases after 7-10 days (9,42). In one recent well-known recent experiment, Albert et al. with considering the age of participants found the sensitivity of RDTs is lower in pediatrics than adults (8).

Some recent attention has focused on the benefits of rapid Abs COVID-19 detection as one of the point-of-care tests. Our findings demonstrated that the rapid Ab detection has lower sensitivity than RDTs; it is accompanied by high false positives. Pere et al., in their investigation, showed a history of recent infection with cold Abs increase the false positive Ab rapid test, especially for IgM, which reduce the validation of the test (10). Fabre et al. performed a similar survey, but in pregnancy, surprisingly, their findings showed, the false positive is higher in pregnant women (29). One reason for the low accuracy of the rapid Ab test can be pointed out to the short-term immunity in such patients (43).
Much of the current systematic and meta-analysis literature focused on the accuracy of serological tests, and as the expected, their findings have shown lower accuracy of serological tests (44–46).

Conclusion

The main goal of the current study was to determine the accuracy of RDTs. This study has found that generally, as the expected, RDTs have lower sensitivity than RT-PCR; this issue is affected by several factors such as type of specimen, the timing of sampling, type of assay, and viral load. This research extends our knowledge of how to improve the sensitivity of RDTs to better diagnose of infected patients to address the controlling COVID-19 pandemic.

Acknowledgment

No funding was received for the present study.

Authors’ Contributions

F.R. conceived the manuscript and revised it. M.E and N.N done the statistical analysis and wrote the manuscript, and prepared tables and figures.

Conflict of interest

The authors declare no conflict of interest. All procedure performs in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or compare ethical strand.
**Figure 1.** Flow diagram of the study selection process.

Records identified through database searching (PubMed=104, Web of science=168, Scopus=198, Embase=276, and Cochrane library=37)

Total = 783

Records after duplicates removed (n = 580)

Records screened (n = 460)

Full-text articles assessed for eligibility (n = 165)

Studies included in qualitative synthesis (n = 20)

Studies included in quantitative synthesis (meta-analysis) (n = 20)

Records excluded

Title and abstract irrelevant to the topic (n = 120)

Full-text articles excluded, with reasons (n = 295)

Review = 107, Letter = 3, Case reports = 5, Commentary = 11, Meeting abstract = 80, Book chapter = 17, Ongoing trials = 27, Observational studies = 45

Full-text articles excluded, with reasons (n = 137)

Ineligible study design = 47, Ineligible index test = 21, Ineligible population = 35, Ineligible outcome = 21, Inadequate sample size = 8, Accuracy data cannot be extracted = 3, Retracted studies = 2
Table 1. Pooled analysis of sensitivity and specificity of included studies with 95% confidence interval.

| Study ID          | Sensitivity         | Specificity         | Positive LR         | Negative LR         | DOR |
|-------------------|---------------------|---------------------|---------------------|---------------------|-----|
| Agullo et al. (27)| 0.576 (0.487-0.661) | 0.998 (0.989-1.000) | 299.39 (42.023-2133.1) | 0.425 (0.348-0.519) | 704.36 (96.091-5163) |
| Agullo et al. (27)| 0.447 (0.360-0.536) | 1.000 (0.993-1.000) | 472.42 (29.398-7591.7) | 0.553 (0.475-0.645) | 854.05 (52.241-13962.1) |
| Agullo et al. (27)| 0.231 (0.160-0.317) | 1.000 (0.992-1.000) | 228.93 (14.076-3723.5) | 0.767 (0.696-0.846) | 298.41 (18.060-4930.7) |
| Agullo et al. (27)| 0.496 (0.404-0.588) | 1.000 (0.992-1.000) | 485.98 (30.265-7803.7) | 0.505 (0.423-0.602) | 963.08 (58.809-15771.9) |
| Abdelrazik et al.| 0.431 (0.359-0.505) | 1.000 (0.989-1.000) | 286.33 (17.860-4590.3) | 0.570 (0.503-0.645) | 502.65 (30.910-8173.8) |
| Albert et al. (21)| 0.796 (0.665-0.894) | 1.000 (0.990-1.000) | 567.87 (35.470-9091.7) | 0.209 (0.125-0.350) | 2712.1 (157.06-46833.5) |
| Ciotti et al. (6)| 0.308 (0.170-0.476) | 1.000 (0.715-1.000) | 7.500 (0.478-117.57)  | 0.717 (0.564-0.912) | 10.455 (0.570-191.78)  |
| Kohmer et al. (7)| 0.290 (0.204-0.389) | 0.250 (0.169-0.347) | 0.387 (0.279-0.536)  | 2.840 (1.978-4.078)  | 0.136 (0.073-0.255)  |
| Kohmer et al. (7)| 0.320 (0.230-0.421) | 0.260 (0.177-0.357) | 0.432 (0.318-0.589)  | 2.615 (1.830-3.737)  | 0.165 (0.090-0.305) |
| Kohmer et al. (7)| 0.180 (0.110-0.269) | 0.260 (0.177-0.357) | 0.243 (0.158-0.375)  | 3.154 (2.238-4.445)  | 0.077 (0.039-0.152) |
| Kohmer et al. (7)| 0.370 (0.276-0.472) | 0.260 (0.177-0.357) | 0.500 (0.378-0.662)  | 2.423 (1.685-3.484)  | 0.206 (0.113-0.377)  |
| Linares et al. (22)| 0.157 (0.114-0.207)| 0.922 (0.881-0.951) | 2.000 (1.203-3.324) | 0.915 (0.858-0.975) | 2.186 (1.239-3.857) |
| Nalumansia et al. (23)| 0.700 (0.594-0.792)| 0.924 (0.874-0.959) | 9.262 (5.398-15.891) | 0.325 (0.236-0.446) | 28.538 (13.848-58.814) |
| Pilarowski et al. (34)| 0.023 (0.008-0.053)| 0.960 (0.925-0.982) | 0.576 (0.196-1.691) | 1.018 (0.984-1.052) | 0.566 (0.187-1.717) |
| Pilarowski et al. (34)| 0.556 (0.212-0.863)| 0.503 (0.462-0.545) | 1.119 (0.620-2.018) | 0.883 (0.423-1.841) | 1.267 (0.337-4.767) |
| Salvagno et al. (31)| 0.340 (0.288-0.394)| 0.994 (0.978-0.999) | 54.500 (13.575-218.81) | 0.665 (0.614-0.719) | 82.007 (20.035-335.66) |
| Schildgen et al. (32)| 0.329 (0.223-0.449)| 0.877 (0.779-0.942) | 2.667 (1.332-5.338) | 0.766 (0.638-0.919) | 3.483 (1.486-8.162) |
| Schildgen et al. (32)| 0.500 (0.381-0.619)| 0.781 (0.669-0.869) | 2.281 (1.399-3.721) | 0.640 (0.495-0.829) | 3.563 (1.738-7.302) |
| Schildgen et al. (32)| 0.877 (0.779-0.942)| 0.795 (0.684-0.880) | 4.267 (2.696-6.753) | 0.155 (0.083-0.289) | 27.496 (11.184-67.599) |
| Scohy et al. (24)| 0.387 (0.291-0.472) | 1.000 (0.916-1.000) | 32.608 (2.053-517.87) | 0.628 (0.544-0.725) | 51.913 (3.118-864.30) |
| Toptan et al. (25)| 0.500 (0.319-0.681) | 1.000 (0.907-1.000) | 39.000 (2.432-625.53) | 0.506 (0.359-0.714) | 77.000 (4.357-1360.8) |
| Study                             | p-value     | 95% CI        | Median         | Median 95% CI | Median 99% CI | Median 0.95% CI |
|----------------------------------|-------------|---------------|----------------|---------------|---------------|----------------|
| Torres et al. (26)              | 0.060       | (0.043-0.081) | 77.000         | (4.741-1250.6) | 0.940         | (0.922-0.959)   |
| CK Mak et al. (18)              | 0.343       | (0.191-0.522) | 25.000         | (1.538-406.50) | 0.662         | (0.520-0.843)   |
| CK Mak et al. (18)              | 0.457       | (0.288-0.634) | 33.000         | (2.057-529.44) | 0.549         | (0.406-0.744)   |
| CK Mak et al. (18)              | 0.111       | (0.037-0.241) | 11.000         | (0.626-193.25) | 0.890         | (0.797-0.994)   |
| CK Mak et al. (18)              | 0.400       | (0.257-0.557) | 37.000         | (2.297-595.89) | 0.604         | (0.476-0.768)   |
| Prince-Guerra et al. (35)       | 0.525       | (0.467-0.583) | 409.57         | (152.91-1097.0)| 0.476         | (0.422-0.536)   |
| Courtellemont et al. (9)        | 0.967       | (0.918-0.991) | 246.56         | (15.502-3921.4)| 0.037         | (0.015-0.092)   |
| Courtellemont et al. (9)        | 0.706       | (0.525-0.849) | 49.000         | (3.100-774.56) | 0.304         | (0.183-0.506)   |
| Pere et al. (10)                | 0.958       | (0.857-0.995) | 49.833         | (7.147-347.45) | 0.042         | (0.011-0.165)   |
| Pere et al. (10)                | 0.917       | (0.800-0.977) | 6.810          | (3.401-13.636) | 0.096         | (0.037-0.248)   |
| Pere et al. (10)                | 0.923       | (0.749-0.991) | 45.37          | (2.910-707.30) | 0.094         | (0.029-0.308)   |
| Pere et al. (10)                | 0.979       | (0.889-0.999) | 50.917         | (7.306-354.84) | 0.021         | (0.003-0.148)   |
| Pere et al. (10)                | 0.915       | (0.796-0.976) | 5.947          | (3.125-11.316) | 0.101         | (0.039-0.259)   |
| Fabre et al. (29)               | 0.041       | (0.017-0.083) | 1.000          | (0.359-2.789)  | 1.000         | (0.957-1.045)   |
| Cerutti et al. (36)             | 0.706       | (0.612-0.790) | 312.82         | (19.576-4998.8)| 0.296         | (0.222-0.395)   |
| Montesinosa et al. (30)         | 0.719       | (0.632-0.795) | 104.69         | (6.597-1661.4) | 0.285         | (0.216-0.375)   |
| Montesinosa et al. (30)         | 0.688       | (0.600-0.766) | 16.500         | (5.417-50.263) | 0.326         | (0.251-0.424)   |
| Montesinosa et al. (30)         | 0.711       | (0.624-0.788) | 103.56         | (6.525-1643.6) | 0.293         | (0.223-0.384)   |
Figure 2. A forest plot showing the estimates for sensitivity (a) and specificity (b) as overall.
Overall

Nasopharyngeal swab

Throat washing and Bronchoalveolar fluids
Figure 3. Summary receiver operating characteristic curve (ROC curve). Estimates of sensitivity and specificity for each study are
References:

1. Wiersinga WJ, Rhodes A, Cheng AC, Peacock SJ, Prescott HC. Pathophysiology, Transmission, Diagnosis, and Treatment of Coronavirus Disease 2019 (COVID-19): A Review. JAMA - Journal of the American Medical Association. 2020.

2. Singanayagam A, Patel M, Charlett A, Bernal JL, Saliba V, Ellis J, et al. Duration of infectiousness and correlation with RT-PCR cycle threshold values in cases of COVID-19, England, January to May 2020. Eurosurveillance. 2020;

3. Uwamino Y, Wakui M, Aoki W, Kurafuji T, Yanagita E, Morita M, et al. Evaluation of the usability of various rapid antibody tests in the diagnostic application for COVID-19. Ann Clin Biochem. 2021;

4. Li Z, Yi Y, Luo X, Xiong N, Liu Y, Li S, et al. Development and Clinical Application of A Rapid IgM-IgG Combined Antibody Test for SARS-CoV-2 Infection Diagnosis. J Med Virol. 2020 Feb;

5. Ricks S, Kendall EA, Dowdy DW, Sacks JA, Schumacher SG, Arinaminpathy N. Quantifying the potential value of antigen-detection rapid diagnostic tests for COVID-19: A modelling analysis. medRxiv. 2020.

6. Ciotti M, Maurici M, Pieri M, Andreoni M, Bernardini S. Performance of a rapid antigen test in the diagnosis of SARS-CoV-2 infection. J Med Virol. 2021;(January):1–4.

7. Kohmer N, Toptan T, Pallas C, Karaca O, Pfeiffer A, Westhaus S, et al. The Comparative Clinical Performance of Four SARS-CoV-2 Rapid Antigen Tests and Their Correlation to Infectivity In Vitro. J Clin Med. 2021;10(2):328.

8. Albert E, Torres I, Bueno F, Huntley D, Molla E, Martínez M, et al. Field evaluation of a rapid antigen test (Panbio™ COVID-19 Ag Rapid Test Device) for COVID-19 diagnosis in primary healthcare centres. 2020;(January).

9. Courtellemont L, Guinard J, Guillaume C, Giaché S, Rzepecki V, Seve A, et al. High performance of a novel antigen detection test on nasopharyngeal specimens for diagnosing SARS-CoV-2 infection. J Med Virol [Internet]. 2021 Mar [cited 2021
10. Péré H, Mboumba Bouassa RS, Tonen-Wolyec S, Podglajen I, Veyer D, Bélec L. Analytical performances of five SARS-CoV-2 whole-blood finger-stick IgG-IgM combined antibody rapid tests. J Virol Methods. 2021;290(November 2020).

11. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, et al. Meta-analysis of observational studies in epidemiology: A proposal for reporting. J Am Med Assoc. 2000;

12. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. In: Journal of clinical epidemiology. 2009.

13. Cheung MWL, Ho RCM, Lim Y, Mak A. Conducting a meta-analysis: Basics and good practices. Int J Rheum Dis. 2012;

14. Lim RBC, Zhang MWB, Ho RCM. Prevalence of all-cause mortality and suicide among bariatric surgery cohorts: A meta-analysis. International Journal of Environmental Research and Public Health. 2018.

15. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;

16. Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. J Natl Cancer Inst. 1959;

17. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. British Medical Journal. 2003.

18. Mak GC, Cheng PK, Lau SS, Wong KK, Lau CS, Lam ET, et al. Evaluation of rapid antigen test for detection of SARS-CoV-2 virus. J Clin Virol. 2020;

19. Cerutti F, Burdino E, Milia MG, Allice T, Gregori G, Bruzzone B, et al. Urgent need of rapid tests for SARS CoV-2 antigen detection: Evaluation of the SD-Biosensor antigen test for SARS-CoV-2. J Clin Virol [Internet]. 2020;132(September):104654. Available from: https://doi.org/10.1016/j.jcv.2020.104654
20. Abdelrazik AM, Elshafie SM, Abdelaziz HM. Potential Use of Antigen-Based Rapid Test for SARS-CoV-2 in Respiratory Specimens in Low-Resource Settings in Egypt for Symptomatic Patients and High-Risk Contacts. Lab Med. 2020;2–5.

21. Albert E, Torres I, Bueno F, Huntley D, Molla E, Fernández-Fuentes MA, et al. Field evaluation of a rapid antigen test (Panbio™ COVID-19 Ag Rapid Test Device) for COVID-19 diagnosis in primary healthcare centres. Clin Microbiol Infect. 2020;

22. Linares M, Pérez-Tanoira R, Carrero A, Romanyk J, Pérez-García F, Gómez-Herruz P, et al. Panbio antigen rapid test is reliable to diagnose SARS-CoV-2 infection in the first 7 days after the onset of symptoms. J Clin Virol. 2020;

23. Nalumansi A, Lutalo T, Kayiwa J, Wateria C, Balinandi S, Kiconco J, et al. Field evaluation of the performance of a SARS-CoV-2 antigen rapid diagnostic test in Uganda using nasopharyngeal samples. Int J Infect Dis. 2021;

24. Scohy A, Anantharajah A, Bodéus M, Kabamba-Mukadi B, Verroken A, Rodriguez-Villalobos H. Low performance of rapid antigen detection test as frontline testing for COVID-19 diagnosis. J Clin Virol. 2020;

25. Toptan T, Eckermann L, Pfeiffer AE, Hoehl S, Ciesek S, Drosten C, et al. Evaluation of a SARS-CoV-2 rapid antigen test: Potential to help reduce community spread? J Clin Virol. 2021;

26. Torres I, Poujois S, Albert E, Colomina J, Navarro D. Evaluation of a rapid antigen test (Panbio™ COVID-19 Ag rapid test device) for SARS-CoV-2 detection in asymptomatic close contacts of COVID-19 patients. Clin Microbiol Infect. 2021;

27. Agulló V, Fernández-González M, Ortiz de la Tabla V, Gonzalo-Jiménez N, García JA, Masiá M, et al. Evaluation of the rapid antigen test Panbio COVID-19 in saliva and nasal swabs in a population-based point-of-care study. Journal of Infection. 2020.

28. Eshghifar N, Busheri A, Shrestha R, Beqaj S. Evaluation of Analytical Performance of Seven Rapid Antigen Detection Kits for Detection of SARS-CoV-2 Virus. Int J Gen Med. 2021;Volume 14:435–40.

29. Fabre M, Ruiz-Martinez S, Monserrat Cantera ME, Cortizo Garrido A, Beunza
Fabra Z, Peran M, et al. SARS-CoV-2 immunochromatographic IgM/IgG rapid test in pregnancy: A false friend? Ann Clin Biochem. 2020;0(0):1–4.

30. Montesinos I, Gruson D, Kabamba B, Dahma H, Van den Wijngaert S, Reza S, et al. Evaluation of two automated and three rapid lateral flow immunoassays for the detection of anti-SARS-CoV-2 antibodies. J Clin Virol [Internet]. 2020;128(April):104413. Available from: https://doi.org/10.1016/j.jcv.2020.104413

31. Salvagno GL, Gianfilippi G, Bragantini D, Henry BM, Lippi G. Clinical assessment of the Roche SARS-CoV-2 rapid antigen test. Diagnosis. 2021;

32. Schildgen V, Demuth S, Lüsebrink J, Schildgen O. Limits and opportunities of sars-cov-2 antigen rapid tests: An experienced-based perspective. Pathogens. 2021;10(1):1–7.

33. Prazuck T, Colin M, Giachè S, Gubavu C, Seve A, Rzepecki V, et al. Evaluation of performance of two SARS-CoV-2 Rapid IgM-IgG combined antibody tests on capillary whole blood samples from the fingertip. PLoS One. 2020;

34. Pilarowski G, Lebel P, Sunshine S, Liu J, Crawford E, Marquez C, et al. Performance characteristics of a rapid SARS-CoV-2 antigen detection assay at a public plaza testing site in San Francisco. medRxiv. 2020.

35. Prince-Guerra JL, Almendares O, Nolen LD, Gunn JKL, Dale AP, Buono SA, et al. Evaluation of Abbott BinaxNOW Rapid Antigen Test for SARS-CoV-2 Infection at Two Community-Based Testing Sites — Pima County, Arizona, November 3–17, 2020. MMWR Morb Mortal Wkly Rep. 2021;70(3):100–5.

36. Cerutti F, Burdino E, Milia MG, Allice T, Gregori G, Bruzzone B, et al. Urgent need of rapid tests for SARS CoV-2 antigen detection: Evaluation of the SD-Biosensor antigen test for SARS-CoV-2. J Clin Virol. 2020;

37. Abdelrazik AM, Elshafie SM, Abdelaziz HM. Potential Use of Antigen-Based Rapid Test for SARS-CoV-2 in Respiratory Specimens in Low-Resource Settings in Egypt for Symptomatic Patients and High-Risk Contacts. Lab Med. 2020;

38. Yamayoshi S, Sakai-Tagawa Y, Koga M, Akasaka O, Nakachi I, Koh H, et al.
Comparison of Rapid Antigen Tests for COVID-19. Viruses. 2020;

39. Nalumansi A, Lutalo T, Kayiwa J, Wateria C, Balinandi S, Kiconco J, et al. 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. 2020;(January).

40. Pilarowski G, Lebel P, Sunshine S, Liu J, Crawford E, Marquez C, et al. Performance characteristics of a rapid SARS-CoV-2 antigen detection assay at a public plaza testing site in San Francisco. medRxiv. 2020;415–8.

41. Krüttgen A, Cornelissen CG, Dreher M, Hornef MW, Imöhl M, Kleines M. Comparison of the SARS-CoV-2 Rapid antigen test to the real star Sars-CoV-2 RT PCR kit. J Virol Methods. 2021;

42. Cevik M, Tate M, Lloyd O, Maraolo AE, Schafers J, Ho A. SARS-CoV-2, SARS-CoV, and MERS-CoV viral load dynamics, duration of viral shedding, and infectiousness: a systematic review and meta-analysis. The Lancet Microbe. 2021;

43. Augustine R, Das S, Hasan A, S A, Abdul Salam S, Augustine P, et al. Rapid Antibody-Based COVID-19 Mass Surveillance: Relevance, Challenges, and Prospects in a Pandemic and Post-Pandemic World. J Clin Med. 2020;

44. Lisboa Bastos M, Tavaziva G, Abidi SK, Campbell JR, Haraoui LP, Johnston JC, et al. Diagnostic accuracy of serological tests for covid-19: Systematic review and meta-analysis. BMJ. 2020;

45. Böger B, Fachi MM, Vilhena RO, Cobre AF, Tonin FS, Pontarolo R. Systematic review with meta-analysis of the accuracy of diagnostic tests for COVID-19. Am J Infect Control. 2021;

46. La Marca A, Capuzzo M, Paglia T, Roli L, Trenti T, Nelson SM. Testing for SARS-CoV-2 (COVID-19): a systematic review and clinical guide to molecular and serological in-vitro diagnostic assays [Internet]. Vol. 41, Reproductive BioMedicine Online. Elsevier Ltd; 2020 [cited 2021 Mar 14]. p. 483–99. Available from: https://pubmed.ncbi.nlm.nih.gov/32651106/
