Safety and efficacy of hydroxychloroquine as prophylactic against COVID-19 in healthcare workers: a meta-analysis of randomised clinical trials

Hwanhee Hong,1,2 Anne Friedland,3 Mengyi Hu,1 Kevin J Anstrom,4 Susan Halabi,2,5 John E McKinnon,6 Ravi Amaravadi,7 Jorge Rojas-Serrano,8 Benjamin S Abella,7 Angélica Margarita Portillo-Vázquez,9 Christopher W Woods,2 Adrian F Hernandez,2 David R Boulware,10 Susanna Naggie,1,2 Radha Rajasingham10

ABSTRACT
Objective We studied the safety and efficacy of hydroxychloroquine (HCQ) as pre-exposure prophylaxis for COVID-19 in healthcare workers (HCWs), using a meta-analysis of randomised controlled trials (RCTs).

Data sources PubMed and EMBASE databases were searched to identify randomised trials studying HCQ.

Study selection Ten RCTs were identified (n=5079 participants).

Data extraction and synthesis The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were used in this systematic review and meta-analysis between HCQ and placebo using a Bayesian random-effects model. A pre-hoc statistical analysis plan was written.

Main outcomes The primary efficacy outcome was PCR-confirmed SARS-CoV-2 infection and the primary safety outcome was incidence of adverse events. The secondary outcome included clinically suspected SARS-CoV-2 infection.

Results Compared with placebo, HCWs randomised to HCQ had no significant difference in PCR-confirmed SARS-CoV-2 infection (OR 0.92, 95% credible interval (CI): 0.58, 1.37) or clinically suspected SARS-CoV-2 infection (OR 0.78, 95% CI: 0.57, 1.01), but significant difference in adverse events (OR 1.35, 95% CI: 1.03, 1.73).

Conclusions and relevance Our meta-analysis of 10 RCTs investigating the safety and efficacy of HCQ as pre-exposure prophylaxis in HCWs found that compared with placebo, HCQ does not significantly reduce the risk of confirmed or clinically suspected SARS-CoV-2 infection, while HCQ significantly increases adverse events.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ Bayesian meta-analysis models with random effects fitted the data.
⇒ The 10 trials included in the meta-analysis represent wide geographical locations including the USA, Canada, Mexico, India, Spain, Bolivia, Venezuela, Peru and Pakistan.
⇒ The findings can be applied to healthcare workers but should not be generalised to a broader population.

INTRODUCTION
Early during the SARS-CoV-2 pandemic, based on in vitro antiviral activity of both chloroquine and hydroxychloroquine (HCQ) against SARS-CoV-2,1–3 clinicians considered use of HCQ for treatment and prevention of SARS-CoV-2 infection and the associated disease, COVID-19. While there are now published randomised controlled trials (RCTs) of HCQ for the treatment of COVID-19 in the inpatient and outpatient setting,4,5 there remains a lack of adequately powered RCTs of HCQ for the pre-exposure prophylaxis (PrEP) of SARS-CoV-2 infection. A number of COVID-19 clinical studies including PrEP studies were planned early in the pandemic; however, several never opened to enrolment and those that did open were closed early without reaching full accrual due to the rapidly changing landscape of preventative therapies, including vaccines, and a significant shift in public opinion of HCQ as a medical intervention for SARS-CoV-2.6,7

Vaccination access remains insufficient globally.7 Specifically, in low-income countries, only 33% of healthcare workers (HCWs) are fully vaccinated. While high-income countries have better coverage, overall, 38% of countries did not achieve the milestone of 70% vaccination coverage for HCWs by
METHODS
The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were used in this systematic review and meta-analysis. A statistical analysis plan was written in advance and the review protocol was registered at PROSPERO (CRD42021285093).

Search strategy and information sources
We searched PubMed/Medline and Ovid/EMBASE databases from database inception through the final search date, 14 March 2023. We used keywords related to COVID-19, HCQ, and RCTs. The full search strategies are provided in online supplemental table 1.

Eligibility criteria and study selection
The eligibility criteria included phase II or phase III RCTs of HCQ for use as PrEP in HCWs with moderate to high risk of exposure. We excluded observational studies, crossover trials, studies where the method of allocation to treatment was not truly random, duplicate studies and non-original data studies. No language, publication date or publication status restrictions were applied. References of prior systematic reviews and meta-analyses were also screened for related studies. Study selection involved screening of titles and abstracts followed by full-text evaluation of possible eligible studies.

Data collection process
Each of the selected studies was independently reviewed by two reviewers (AF, MH or HH). We extracted data on the study design, baseline characteristics, interventions and outcomes. Any disagreements of collected information between reviews were reconciled through discussion by all three reviewers.

Outcome measures
The primary efficacy outcome for the meta-analysis was laboratory-confirmed SARS-CoV-2 infection by PCR test and the primary safety outcome was incidence of adverse events (table 1). The secondary efficacy outcome was suspected or probable SARS-CoV-2 infection. Included studies had the following outcome definitions: (1) laboratory-confirmed SARS-CoV-2 infection defined as COVID-19-like symptoms and positive SARS-CoV-2 PCR and (2) suspected or probable SARS-CoV-2 infection defined as COVID-19-like symptoms but lack of confirmatory PCR testing.

Treatment assignment
Our meta-analysis did not study HCQ dosing-specific effects. For studies randomising participants to more than one HCQ arm with different doses, all HCQ arms were merged and considered as a single HCQ arm. Such studies included the Rajasingham et al, McKinnon et al and Syed et al studies.12 15 17

Risk of bias and certainty of evidence assessment
Two independent reviewers (AF, HH) assessed the risk of bias (low, intermediate, high) of the included studies using the Cochrane’s Collaboration tool18 (online supplemental table 2). We assessed the certainty of evidence using the Grades of Recommendation Assessment, Development and Evaluation (GRADE) approach.19

Statistical analysis
Bayesian logistic regression meta-analysis models under two assumptions (fixed effects and random effects) were fitted to estimate the OR of having an outcome between HCQ and placebo. The fixed-effects model assumes that the OR is constant across studies, while the random-effects model accounts for heterogeneity in the ORs across studies. To assess and compare the goodness of fit of the fitted fixed-effects and random-effects models, we calculated the Watanabe-Akaike information criterion.21 In the Bayesian models, we assigned non-informative prior distributions as no prior information was available. The ORs and the associated 95% credible intervals (CIs) were estimated using Markov chain Monte Carlo (MCMC) algorithms. In addition, we calculated Bayesian posterior probabilities of the OR smaller than 1 or 0.5 for the primary efficacy outcome, and greater than 2 for the safety outcome.22 The SD of the random effects and I²23 were estimated to quantify the between-study heterogeneity, where small values of both metrics indicate slight heterogeneity. To identify publication bias, we plotted and assessed funnel plots for their symmetry and conducted the Egger’s test.24 All Bayesian meta-analyses were conducted using the rstan package (V.2.21.2)25 in R V.4.0.2.26 We used two parallel chains, where each chain consists of 50000 samples after a 25 000-sample burn-in. We checked convergence of the MCMC chains for all model parameters using trace plots and Gelman-Rubin diagnostic statistics.27

Patient and public involvement
No patient involved.
| Naggie et al.13 (HERO-HCQ) NCT04334148 | Confirmed (by NP swab PCR) or suspected COVID-19 infection through 30 days | 60 days | HCQ | HCQ 600mg two times per day loading dose for day 1, followed by 400mg four times a day for 29 days | 683 |
| Abella et al.11 (PATCH) NCT04329923 | COVID-19 infection as determined by positive NP swab over 8 weeks | 56 days (8 weeks) | HCQ | HCQ 600mg daily for 60 days | 64 |
| Rajasingham et al.12 (MN-COVID-PREP) NCT04328467 | COVID-19-free survival time by lab-confirmed or probable illness | 84 days (12 weeks) | HCQ* | HCQ loading doses (400mg two times 6–8 hours apart), followed by 400mg once weekly or 400mg two times per week for 84 days | 989 |
| Rojas-Serrano et al.14 | Time to symptomatic respiratory infection with a positive COVID-19 RT-PCR over 60 days | 60 days | HCQ | HCQ 200mg daily for 60 days | 62 |
| McKinnon et al.15 (WHIP) NCT04341441 | Lab-confirmed cases of COVID-19 determined by either IgM and IgG serology in blood sample or RT-PCR test results Confirmed new cases of COVID-19 | 56 days (8 weeks) | HCQ* | HCQ 400mg loading dose for day 1, followed by 200mg daily or 400mg weekly on the same day of each week for 56 days | 387 |
| Tirupakuzhi Vijayaraghavan et al.36 CTRI/2020/05/025067 | Lab-confirmed SARS-CoV-2 infection by PCR or presence of antibodies | 180 days (6 months) | HCQ | HCQ 400mg two times on the day of enrolment, followed by 400mg once a week for a total of 12 weeks plus personal protective equipment (PPE) | 213 |
| Polo et al.37 (EPICOS) NCT04334928 | Lab-confirmed symptomatic COVID-19 by PCR | 84 days (12 weeks) | HCQ† | HCQ 200mg once daily | 231 |
| Llanos-Cuentas et al.30 | COVID-19 cases confirmed by PCR or serological test | 28 days (4 weeks) | HCQ | HCQ loading dose of 600mg on the first day, followed by 400mg every other day plus PPE | 36 |
| Grau-Pujol et al.38 NCT04331834 | COVID-19 confirmed cases with seroconversion or PCR test | 180 days (6 months) | HCQ | HCQ 400mg daily for 4 consecutive days, followed by 400mg weekly | 142 |
| Syed et al.17 NCT04359537 | COVID-19-free survival (COVID-19 confirmed by PCR) | 84 days (12 weeks) | HCQ* | HCQ 400mg two times for day 1, followed by 400mg weekly or HCQ 400mg once every 3 weeks or HCQ 200mg once every 3 weeks | 154 |

*More than one HCQ group with different doses are lumped.
†The Polo et al study randomised participants to four treatment groups, and the HCQ and control groups are used in our meta-analysis.

HCQ, hydroxychloroquine; NP, nasopharyngeal; RT-PCR, reverse transcription PCR.
RESULTS
Search results
Our database search resulted in 350 unique studies after excluding duplicates. Of those, 339 studies were screened out due to irrelevance based on title and abstract screening. Eleven studies were assessed in full text for eligibility (figure 1). Of those, one trial was excluded from the meta-analysis because it studied with non-HCW populations. As a result, a total of 10 studies in a population consisting of HCWs were identified (table 1).

Study and patient characteristics
Study design, population, treatment strategies and key characteristics are presented in table 1 and online supplemental table 3. A total of 5079 randomised participants (2961 randomised to HCQ) from the 10 studies were included in the meta-analysis. The 10 studies defined HCWs broadly and included first responders (emergency medical services, fire and police). The follow-up duration of the 10 studies ranged from 28 days to 180 days. The HCQ dosing scheme varied across studies, including daily dosing ranging from 200 to 600 mg daily with or without a loading dose and once or two times a week or once every 3 weeks dosing. The duration of therapy also varied across studies (table 1). The trial-specific definitions of primary outcome and adverse events are comparable across trials (table 1 and online supplemental table 4).

Baseline characteristics by randomised treatment assignment are reported (online supplemental table 5). The average age ranged between 31 and 45 years. The aggregate proportion of women within each study varied across the 10 trials, with a range from 44% to 69%. In addition, the Abella et al and Rojas-Serrano et al studies had smaller sample size compared with the other three studies and showed a difference in female ratio between placebo and HCQ groups. In the Naggie et al,13 Abella et al, Rajasingham et al and McKinnon et al studies, over 80% of study participants were white. The Abella et al and Rajasingham et al studies had high proportions of HCWs.
working in an emergency department (56% and 41%, respectively), and the Abella et al. study had a high proportion of nurses (67%).

Several studies reported treatment adherence assessed by two methods: self-reported adherence and/or pill count at the end of the study. The Rajasingham et al. study additionally conducted remote blood sampling to verify HCQ concentrations in a subset. Adherence varied significantly across the studies, with a low proportion of approximately 52% in the Rojas-Serrano et al. study and 97%–98% in the Abella et al. study.

Results of meta-analysis

Overall, 3.4% (171 of 5039) developed PCR-confirmed SARS-CoV-2 infection and 5.6% (230 of 4087) developed suspected COVID-19 that was not laboratory confirmed. Since the goodness-of-fit assessment using Watanabe-Akaike information criterion concluded that the random-effects meta-analysis model was as good as or better than the fixed-effects meta-analysis model for all outcomes, we reported the results under the random-effects model. Compared with placebo, HCWs randomised to HCQ had numerically lower rate of PCR-confirmed SARS-CoV-2 infection cases (OR 0.92, 95% CI: 0.58, 1.37; GRADE score: moderate certainty), and suspected or probable SARS-CoV-2 infection cases (OR 0.78, 95% CI: 0.57, 1.10; GRADE score: moderate certainty). None of these ORs were statistically significant. Participants treated with HCQ had a numerically higher rate of adverse events (OR 1.35, 95% CI: 1.03, 1.73; GRADE score: moderate certainty) with statistical significance (figure 2). The outcome data used in our analyses are presented in online supplemental table 6. The summary of GRADE score assessment is provided in online supplemental table 7.

The Bayesian posterior probabilities of the OR less than 1 for the confirmed SARS-CoV-2 infection outcome (ie, the probability of HCQ favouring over placebo) was 0.67, while the posterior probability of OR less than 0.5 (ie, the probability that the odds of having a confirmed SARS-CoV-2 infection outcome in HCQ is less than a half of the odds in placebo) was 0.009. The posterior probability of the OR greater than 2 for the adverse event outcome (ie, the probability that the odds of having an adverse event in HCQ is greater than twice of the odds in placebo) was 0.004.

Our meta-analysis showed little or moderate variability of effect estimates across studies with I² value of 0%, 0% and 45%, and the estimated SD of the random effects of 0.39, 0.26 and 0.45 for the confirmed SARS-CoV-2 infection, suspected SARS-CoV-2 infection and adverse event outcomes, respectively. Funnel plots (online supplemental figure) showed no indication of publication bias and the associated Egger’s test results supported that the funnel plots were not asymmetrical with p values of 0.308, 0.305 and 0.794 for the confirmed SARS-CoV-2 infection, suspected SARS-CoV-2 infection and adverse event outcomes, respectively.

DISCUSSION

Understanding the pre-exposure prophylactic effect of HCQ against COVID-19 remains relevant, as its use continues, particularly in the international setting. Our meta-analysis of the 10 RCTs investigating the safety and efficacy of HCQ as PrEP in 5079 HCWs found that HCQ did not have a statistical association with fewer confirmed or suspected/probable SARS-CoV-2 infection cases compared with placebo. The geographical locations of the 10 trials included in the meta-analysis are the USA, Canada, Mexico, India, Spain, Bolivia, Venezuela, Peru and Pakistan (online supplemental table 3). While the ORs of most studies favour HCQ, the CIs remain wide suggesting low certainty in the true point estimate. Two studies including the Llanos-Cuentas et al. study conducted in Peru and the Syed et al. study conducted in Pakistan showed ORs favouring placebo, though the CIs remain wide. Furthermore, in this population, COVID-19 event rates were low, particularly for the most relevant PCR-confirmed infection outcome. The low event rate raises further concern for the uncertainty of these outcomes. Thus, if there is a minimal effect, the absolute benefit would be low. To gain more certainty, a very large study would need to be done and this is difficult to support now due to availability of highly effective vaccines. The safety profile of HCQ in the outpatient setting is well understood. In these outpatient studies, there was statistically significant difference in adverse events in the HCQ versus the placebo arm, indicating that HCQ is less safe than placebo.

Our findings can be applied to HCWs but should not be generalised to a broader population. Our systematic search found only one published RCT of PrEP for non-HCW populations and the study was excluded from our meta-analysis. This study was conducted in Singapore and showed a significant reduction in the risk of COVID-19 infection in the HCQ arm when compared with the comparator arm, vitamin C. However, this study showed moderate risk of bias as it used an open-label cluster randomisation design, the Institutional Review Board excluded higher risk persons from the HCQ arm only and the participants may not be representative of a general population due to the communal living environment.

A Bayesian meta-analysis approach was used to fit the data. The Bayesian meta-analysis approach has several advantages. First, its flexibility and the MCMC sampling methods to estimate posterior distributions provide probability-based quantities (eg, posterior probability of an OR smaller than 0.5) that complement typical meta-analysis results (eg, ORs and the associated CIs) and help decision-making. Second, the Bayesian meta-analysis model with random effects estimates the between-study variability better than the frequentist counterparts. Third, when it comes to binary outcomes, the Bayesian approach handles rare events better than the frequentist counterparts.
A recently published meta-analysis by García-Albéniz et al. investigated pre-exposure (seven RCTs included) and post-exposure (four RCTs included) prophylactic effects of HCQ, but not limited to the HCW population. They found significant pre-exposure prophylactic effects of HCQ on SARS-CoV-2 infection, different from ours. The seven PrEP RCTs included in the García-Albéniz et al. meta-analysis consisted of six RCTs that were in our meta-analysis and the aforementioned Singapore study that was excluded from our meta-analysis. Our meta-analysis provides the most up-to-date, systematic and comprehensive evidence about prophylactic effects of HCQ focusing on the HCW population.

Although a meta-analysis allows for combining evidence from multiple studies in a principled way, our meta-analysis has limitations. First, our analysis did not evaluate effects of different HCQ doses and combined multiple HCQ arms using different doses in three studies. The RCTs included in our meta-analysis studied varying dosing schemes and a meta-analysis using aggregate-level data is not a sufficient source to study dosing effects. Second, detailed subgroup analyses were not conducted due to

Figure 2  Forest plots of the meta-analysis results showing the number of events (y), sample size (n), posterior median of ORs and the associated 95% credible intervals (CIs) comparing HCQ versus placebo for (A) laboratory-confirmed positive COVID-19, (B) suspected COVID-19 and (C) adverse events. HCQ, hydroxychloroquine.
limited information. Individual-level data are required to study both dosing and subgroup effects.

Our meta-analysis of 10 RCTs investigating safety and efficacy of HCQ as PrEP in HCWs provides the most up-to-date evidence on HCQ. Although most individual trials were underpowered and showed null data, integrating the results systematically via meta-analysis contributes to the scientific literature and provides certain answers to the question. We found that HCQ does not reduce the risk of confirmed or probable SARS-CoV-2 infection, but increase risk of adverse events compared with placebo. HCQ should not be used for PrEP in the HCW population.

Author affiliations
1Department of Biostatistics and Bioinformatics, Duke University, Durham, North Carolina, USA
2Duke Clinical Research Institute, Durham, North Carolina, USA
3Department of Infectious Disease, UNC School of Medicine, Chapel Hill, North Carolina, USA
4Collaborative Studies Coordinating Center, University of North Carolina System, Chapel Hill, North Carolina, USA
5Department of Biostatistics and Bioinformatics, Duke University School of Medicine, Durham, North Carolina, USA
6Division of Infectious Diseases, Henry Ford Hospital, Detroit, Michigan, USA
7Division of Hematology Oncology, University of Pennsylvania, Philadelphia, Pennsylvania, USA
8Intestinal Lung Disease and Rheumatology Units, Instituto Nacional de Enfermedades Respiratorias, Mexico City, Mexico
9Otologyngy Department, Instituto Nacional de Enfermedades Respiratorias, Mexico City, Mexico
10Division of Infectious Diseases & International Medicine, University of Minnesota Twin Cities, Minneapolis, Minnesota, USA

Twitter Ravi Amaravadi @AmaravadiRavi and Jorge Rojas-Serrano @joroser

Contributors HH, SN, RR and KJA designed the study. HH is the guarantor. HH, AF and MH collected and analysed the data. HH, SN and WR wrote the manuscript. SH and KJA provided statistical review, while AF, JEM, RA, JR-P and MH collected and analysed the data. HH, SN and RR wrote the manuscript. SH and KJA provided statistical review, while AF, JEM, RA, JR-P and MH collected and analysed the data. HH, SN and RR wrote the manuscript.

Funding This study is funded by the Patient Centered Outcomes Research Institute (PCORI; contract number COVID-19-2020-001).

Disclaimer The funder had no role in the design, conduct, analysis or reporting of this study.

Competing interests All authors except BSA reported no financial relationship with commercial interest. BSA has received NIH funds for COVID-19-related research and holds equity in VOCI Health, a start-up company that is developing novel COVID-19 testing.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval Ethics approval was not required because this study used publicly available aggregate data that were not involved with patients’ information or prospective data collection.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplemental information.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID ids
Hwaanee Hong http://orcid.org/0000-0002-3736-6237
Ravi Amaravadi http://orcid.org/0000-0002-5768-2474
Susanna Naggie http://orcid.org/0000-0001-7721-6975

REFERENCES
17 Syed F, Hassan M, Arif MA, et al. Pre-exposure prophylaxis with various doses of hydroxychloroquine among Healthcare personnel...


