**ORIGINAL RESEARCH**

**Treatment with ACE inhibitors or ARBs and risk of severe/lethal COVID-19: a meta-analysis**

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**ABSTRACT**

**Objective** It has been hypothesised that the use of ACE inhibitors and angiotensin receptor blockers (ARBs) might either increase or reduce the risk of severe or lethal COVID-19. The findings from the available observational studies varied, and summary estimates are urgently needed to elucidate whether these drugs should be suspended during the pandemic, or patients and physicians should be definitely reassured. This meta-analysis of adjusted observational data aimed to summarise the existing evidence on the association between these medications and severe/lethal COVID-19.

**Methods** We searched MedLine, Scopus and preprint repositories up to 8 June 2020 to retrieve cohort or case–control studies comparing the risk of severe/fatal COVID-19 (either mechanical ventilation, intensive care unit admission or death), among hypertensive subjects treated with: (1) ACE inhibitors, (2) ARBs and (3) both, versus untreated subjects. Data were combined using a random-effect generic inverse variance approach.

**Results** Ten studies, enrolling 9890 hypertensive subjects were included in the analyses. Compared with untreated subjects, those using either ACE inhibitors or ARBs showed a similar risk of severe or lethal COVID-19 (summary OR: 0.90; 95% CI 0.65 to 1.26 for ACE inhibitors; 0.92; 95% CI 0.75 to 1.22 for ARBs). The results did not change when both drugs were considered together, when death was the outcome and excluding the studies with significant, divergent results.

**Conclusion** The present meta-analysis strongly supports the recommendation of several scientific societies to continue ARBs or ACE inhibitors for all patients, unless otherwise advised by their physicians who should thus be reassured.

**INTRODUCTION**

With the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic, evidence is rapidly accumulating on the risk factors of severe COVID-19 and death. In the wake of some preliminary, unadjusted reports, indi- cations of severe COVID-19 and death. In the wake of some preliminary, unadjusted reports,1–4 individuals with pre-existing comorbidities such as hypertension, diabetes and cardiovascular diseases have been identified as those highly vulnerable.5 Notably, such chronic conditions frequently require prescription of ACE inhibitors and angiotensin II receptor blockers (ARBs).6 Animal studies showed that ACE inhibitors and ARBs upregulate ACE2 expression7 and, as coronaviruses bind their target cells through ACE2, concerns have been expressed that these therapies might facilitate infection with SARS-CoV-2 and increase the risk of severe or fatal COVID-19.6,8 In contrast, it has been suggested that ACE inhibitors and ARBs could benefit infected patients, as ACE2 converts angiotensin II (with known vasoconstrictive, proinflammatory and fibrotic effects) into angiotensin 1–7, which may protect lungs from acute injury, and upregulating ACE2 through therapy may enhance this process.9

In this uncertain scenario, some observational studies with multivariable analyses found no association between use of renin–angiotensin–aldosterone system (RAAS) inhibitors and COVID-19 severity.10–16 A few studies found a significant reduction in the risk of death or severe disease17–19 and one study found a increased risk of mechanical ventilation and admission to the intensive care unit (ICU).19 The magnitude of the association also varied across studies, which differed for patients’ characteristics, setting (inpatient or outpatient), population targeted by serological testing protocols and extent of measured confounding.

Summary estimates are urgently needed to elucidate whether these drugs, that are prescribed to tens of millions patients worldwide,19 should be suspended during the pandemic, or patients and physicians should be definitely reassured. We thus carried out a meta-analysis to summarise the existing evidence from adjusted analyses on the association between RAAS inhibitors and COVID-19.

**METHODS**

**Bibliographic search, data extraction and quality assessment**

We searched MEDLINE and Scopus databases, up to 11 May 2020, for studies evaluating the risk of severe and/or fatal COVID-19 among ACE inhibitors and/or ARBs users versus non-users. The following search strategy was adopted, without language restrictions: COVID-19 [Title/Abstract] OR Coronavirus [Title/Abstract] OR SARS-CoV-2 [Title/Abstract] AND angiotensin* [Title/Abstract]. The reference lists of reviews and retrieved articles was also screened for additional pertinent papers. In the context of a public health emergency, there is urgency to make research findings available,21 and several relevant clinical data have been shared in public preprint repositories: we thus extended the search to include any relevant manuscript posted in MedRxiv. Inclusion criteria were: (A) cohort or
 Electronic supplementary material

Cardiac risk factors and prevention

Figure 1 PRISMA 2009 flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Data analysis

Data were combined using a random-effect generic inverse variance approach\(^23\) in order to account for between-study heterogeneity. Missing SEs were computed from 95% CIs following standard Cochrane methodology. If a paper reported the results of different multivariable models, the most stringently controlled estimates (those from the model adjusting for more factors) were extracted. If different models controlled for the same number of covariates, the model containing the most clinically meaningful covariates was used for the analysis.\(^24\)

Between-study heterogeneity was quantified using the I\(^2\) statistic. Potential publication bias was assessed graphically, using funnel plots (displaying the Relative Risks from individual studies on the y-axis and their standard errors on the x-axis). Missing SEs were computed from 95% CIs following standard Cochrane methodology. If a paper reported the results of different multivariable models, the most stringently controlled estimates (those from the model adjusting for more factors) were extracted. If different models controlled for the same number of covariates, the model containing the most clinically meaningful covariates was used for the analysis.\(^24\)

The units of the meta-analysis were single comparisons of: (A) ACE inhibitors, (B) ARBs users and (C) both ACE inhibitors and ARBs users, versus non users, in predicting: (1) severe/lethal COVID-19 (presence of either ICU admission, mechanical ventilation or death) and (2) lethal COVID-19. When a study only reported separate estimates for ACE inhibitors or ARBs users, or for the different outcomes included in the definition of severe/lethal COVID-19 (eg, ICU admission and mechanical ventilation separately), the overall estimate of risk was computed from the separate relative risks using the fixed-effect model for generic inverse variance outcomes.\(^24\)

All meta-analyses were performed using RevMan software, V.5.3 (The Cochrane Collaboration, 2019).

Ethics

The informed consent was not required, as the study did not enrol human subjects.

RESULTS

Of the 553 papers initially retrieved, five case-control and five cohort studies were included in the analyses\(^10\)–\(^19\) (figure 1).

Overall, the studies included 9890 hypertensive subjects; four studies included only COVID-19 symptomatic patients requiring hospitalisation\(^13\)–\(^16\)–\(^18\) (table 1). Six studies were carried out in Europe\(^10\)–\(^12\)\(^14\)\(^16\)–\(^17\) and two in the USA\(^15\)\(^19\) and two in China.\(^13\)\(^18\) The mean age ranged from 58 to 69 years, and the sample size ranged from 205\(^17\) to 6272.\(^14\)

The methodological characteristics of the included studies are summarised in table 2: the selection of the cohort of patients, the ascertainment of the exposure and the evaluation of the comparability of subjects were adequate in all studies, while 8 out of 10 adequately addressed the items pertaining to outcome assessment and follow-up (length and missing data). One study had a high risk of misclassification bias, as the proportions of hypertensive subjects treated with ACE inhibitors (16.4%) or ARBs (13.2%) were particularly low.\(^19\)

Risk of severe/lethal COVID-19

A total of five studies, enrolling 7489 hypertensive patients, were included in the meta-analysis comparing the risk of severe/lethal COVID-19 between ACE inhibitors users versus non-users\(^10\)\(^14\)\(^15\)\(^17\)\(^19\) (table 3, figure 2). Overall, the risk of severe or lethal disease was comparable among treated and untreated patients (summary OR: 0.90; 95% CI 0.65 to 1.26). Two studies showed significant results, with opposite direction. The first included 682 hypertensive subjects and showed an increased risk of severe illness among the 112 patients treated with ACE inhibitors.\(^19\) The second enrolled 105 hypertensive subjects and reported a lower risk among the 38 treated patients.\(^17\) Excluding one or both of these studies did not change the results, which remained non-significant (all p>0.05).

Five studies, enrolling 7462 hypertensive subjects, were included in the meta-analysis comparing the risk of severe illness between ARBs users and non-users\(^10\)\(^13\)–\(^15\)\(^19\) (table 3, figure 3). All of them showed non-significant differences between treated and untreated patients, with a summary OR of 0.92; 95% CI 0.75 to 1.12.

When the above antihypertensive treatments were considered together (five studies, enrolling 11334 hypertensive patients),\(^10\)\(^11\)\(^14\)\(^15\)\(^19\) the risk of developing severe COVID-19 was again comparable between treated and untreated patients (summary OR: 1.00; 95% CI 0.84 to 1.18; figure 4).

Risk of death from COVID-19

The risk of death among RAAS inhibitors users versus non-users was compared in four studies, including a total of 2412
### Table 1  Characteristics of the included studies

<table>
<thead>
<tr>
<th>N</th>
<th>First author</th>
<th>Journal</th>
<th>Country</th>
<th>Study design</th>
<th>No. of infected patients (with severe/lethal COVID-19)</th>
<th>No. of hypertensive patients (under ACEI/ARBs)</th>
<th>Mean age (SD)</th>
<th>% males</th>
<th>Follow-up</th>
<th>Extracted outcome(s)</th>
<th>Method for adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bean</td>
<td>Submitted</td>
<td>UK</td>
<td>Cohort</td>
<td>205 (53)</td>
<td>105 (38)</td>
<td>63.0 (20.0)</td>
<td>51.7</td>
<td>7 days</td>
<td>Severe/lethal COVID-19 (ICU and death).</td>
<td>Logistic regression adjusted for age, gender and comorbidities.</td>
</tr>
<tr>
<td>2</td>
<td>Bravi</td>
<td>Submitted</td>
<td>Italy</td>
<td>Case–control</td>
<td>1603 (192)</td>
<td>543 (458)</td>
<td>58.0 (20.9)</td>
<td>47.3</td>
<td>24 days</td>
<td>(1) Severe/lethal COVID-19 (mech. ventilation, ICU and death); (2) death.</td>
<td>Logistic regression adjusted for age, gender and comorbidities.</td>
</tr>
<tr>
<td>3</td>
<td>de Abajo</td>
<td>The Lancet</td>
<td>Spain</td>
<td>Case–control</td>
<td>1139 (393)</td>
<td>6261 (3950)</td>
<td>69.1 (15.4)</td>
<td>61.0</td>
<td>–</td>
<td>Severe COVID-19 (hospital admission).</td>
<td>Logistic regression adjusted for age, gender, region (matching variables) and comorbidities.</td>
</tr>
<tr>
<td>4</td>
<td>Giorgi Rossi</td>
<td>Submitted</td>
<td>Italy</td>
<td>Cohort</td>
<td>2653 (217)</td>
<td>430 (108)</td>
<td>63.2</td>
<td>50.1</td>
<td>14 days</td>
<td>Death.</td>
<td>Cox proportional hazard analysis adjusted for age, gender and Charlson index.</td>
</tr>
<tr>
<td>5</td>
<td>Liu</td>
<td>Submitted</td>
<td>China</td>
<td>Case–control</td>
<td>511 (381)</td>
<td>78 (22)</td>
<td>65.2 (10.7)</td>
<td>55.2</td>
<td>NR</td>
<td>Severe/lethal COVID-19 (dyspnoea, resp. rate ≥30/min, SaO2 ≤93%, mech. ventilation).</td>
<td>Logistic regression adjusted for gender and medications.</td>
</tr>
<tr>
<td>6</td>
<td>Mancia</td>
<td>NEJM</td>
<td>Italy</td>
<td>Case–control</td>
<td>6272 (617)</td>
<td>3586 (1844)</td>
<td>68.0 (13.0)</td>
<td>63.2</td>
<td>–</td>
<td>Severe/lethal COVID-19 (ICU and death).</td>
<td>Logistic regression adjusted for age, race, comorbidities and medications.</td>
</tr>
<tr>
<td>7</td>
<td>Mehra</td>
<td>NEJM (Retracted)</td>
<td>Multicountry</td>
<td>Cohort</td>
<td>8910 (515)</td>
<td>2346 (1326)</td>
<td>49.0 (16.0)</td>
<td>60.0</td>
<td>40 days</td>
<td>Death.</td>
<td>Logistic regression adjusted for age, race, comorbidities and medications.</td>
</tr>
<tr>
<td>8</td>
<td>Mehta</td>
<td>JAMA Cardiol</td>
<td>USA</td>
<td>Cohort</td>
<td>1735 (272)</td>
<td>682 (202)</td>
<td>64.0 (14.0)</td>
<td>58.5</td>
<td>NR</td>
<td>Severe/lethal COVID-19 (ICU and mech. ventilation).</td>
<td>Logistic regression adjusted for age, gender and comorbidities.</td>
</tr>
<tr>
<td>9</td>
<td>Reynolds</td>
<td>NEJM</td>
<td>USA</td>
<td>Case–control</td>
<td>5894 (1002)</td>
<td>2573 (2141)</td>
<td>64.0 (15.6)</td>
<td>50.8</td>
<td>–</td>
<td>Severe/lethal COVID-19 (mech. ventilation, ICU and death).</td>
<td>Analysis propensity score-matched for age, gender, race, BMI, smoke, comorbidities and medications.</td>
</tr>
<tr>
<td>10</td>
<td>Tedeschi</td>
<td>Clin Infect Dis</td>
<td>Italy</td>
<td>Cohort</td>
<td>609 (179)</td>
<td>311 (175)</td>
<td>68.0 (18.5)</td>
<td>68.0</td>
<td>6 days</td>
<td>Death.</td>
<td>Cox proportional hazard analysis adjusted for age, gender and comorbidities.</td>
</tr>
<tr>
<td>11</td>
<td>Zhang</td>
<td>Circ Res</td>
<td>China</td>
<td>Cohort</td>
<td>1128 (99)</td>
<td>1128 (188)</td>
<td>64.0 (9.0)</td>
<td>53.3</td>
<td>28 days</td>
<td>Death.</td>
<td>Analysis propensity score-matched for age, gender, comorbidities and in-hospital therapy.</td>
</tr>
</tbody>
</table>

*Cases were COVID-19 patients; controls were SARS-CoV-2 negative subjects extracted from primary healthcare databases: as such, the number of hypertensive subjects includes both cases and controls and is higher than the number of COVID-19 patients.

†Number of patients with severe COVID-19 among only those with hypertension.

Included only in sensitivity analyses.

**ARBS**, Angiotensin receptor blockers; ICU, intensive care unit; mech., mechanical; NR, not reported; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

### Table 2  Methodological quality of the included studies according to the Newcastle Ottawa Scale

<table>
<thead>
<tr>
<th>Selection (max score 4)</th>
<th>Comparability (max score 2)</th>
<th>Outcome (max score 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Bravi</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>de Abajo</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Giorgi Rossi</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Liu</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Mancia</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Mehta</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Reynolds</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Tedeschi</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Zhang</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Hypertensive subjects. Overall, no differences in risk emerged between the two groups, with a summary OR of 0.88 (95% CI 0.68 to 1.14; table 3, figure 3). A single study from China, enrolling 1128 hospitalised hypertensive patients, showed a significant risk reduction among treated subjects; when its results were excluded from the analyses, the overall estimates did not change (pooled OR 0.95; 95% CI 0.76 to 1.18). Another study assessed the risk of death among ACE inhibitors/ARBs users versus non users and was initially included in the meta-analysis. However, this study was later retracted; thus, it was excluded from the main analyses and included into a sensitivity analysis: with or without the study, the summary estimate did not change (pooled OR 0.85; 95% CI 0.81 to 1.03).

**DISCUSSION**

Two main findings emerge from the present meta-analysis, which included the adjusted estimates of 10 observational studies and
Table 3  Risk of severe/fatal COVID-19 or death among hypertensive subjects treated with RAAS inhibitors versus untreated subjects, overall and by drug class

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>No. of studies (sample)</th>
<th>Pooled OR (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Severe/fatal COVID-19a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE inhibitors onlya 10,14,15,17-19</td>
<td>5 (7489)</td>
<td>0.90 (0.65 to 1.26)</td>
<td>0.6 80</td>
</tr>
<tr>
<td>ARBs onlya 13-15,19</td>
<td>5 (7462)</td>
<td>0.92 (0.75 to 1.12)</td>
<td>0.4 25</td>
</tr>
<tr>
<td>ARBs/ACE inhibitors 11,14,15,19</td>
<td>5 (11334)</td>
<td>1.00 (0.84 to 1.18)</td>
<td>0.9 50</td>
</tr>
<tr>
<td>2. Death from COVID-19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARBs/ACE inhibitors 10,12,16,18</td>
<td>4 (2412)</td>
<td>0.88 (0.68 to 1.14)</td>
<td>0.3 24</td>
</tr>
<tr>
<td>ARBs/ACE inhibitors 10,12,16,18,25</td>
<td>5 (4758)</td>
<td>0.85 (0.71 to 1.03)</td>
<td>0.10 12</td>
</tr>
</tbody>
</table>

All meta-analyses are based on a generic inverse variance approach.

*aIncluding admission into intensive care unit, need for mechanical ventilation or death.†Including one retracted study.25,26 ARBs, angiotensin receptor blockers; RAAs, renin–angiotensin–aldosterone.

Figure 2  Risk of severe/fatal COVID-19 among ACE inhibitors users versus non-users. ARBs, angiotensin receptor blockers.

Figure 3  Risk of severe/fatal COVID-19 among ARBs inhibitors users, versus non-users. ARBs, angiotensin receptor blockers.

Figure 4  Risk of severe/fatal COVID-19 among ACE inhibitors/ARBs users versus non-users. ARBs, angiotensin receptor blockers.

Figure 5  Risk of death among ACE inhibitors/ARBs users versus non-users. ARBs, angiotensin receptor blockers.
Key messages

What is already known on this subject?
► Some preliminary, unadjusted reports on severe acute respiratory syndrome coronavirus 2 positive subjects showed an increased mortality and morbidity among hypertensive patients, who were frequently treated with ACE inhibitors or angiotensin receptor blockers (ARBs). Recently, some observational studies with multivariable analyses found no association between these medications and COVID-19 severity, a few studies found a significant reduction in the risk of death or severe disease and one study found a increased risk of mechanical ventilation and admission to the intensive care unit. The magnitude of the association also varied across studies, which differed for patients’ characteristics, setting (inpatient or outpatient), population targeted by serological testing protocols and extent of measured confounding.

What might this study add?
► This meta-analysis is based on 10 adjusted observational studies (enrolling almost 10 000 hypertensive subjects), from different countries, and provides the first summary estimate on the association between ACE inhibitors or ARBs use and COVID-19 severity or mortality. All analyses showed a comparable risk of severe or fatal illness among treated and untreated subjects, either considering ACE inhibitors or ARBs separately, or combined.

How might this impact on clinical practice?
► Given that ACE inhibitors and ARBs are prescribed to tens of millions patients worldwide, summary estimates were strongly needed to elucidate whether these drugs should be suspended during the pandemic, or patients and physicians should be definitely reassured. These findings strongly support the recommendation of several scientific societies to continue ARBs or ACE inhibitors medication for all patients, unless otherwise advised by their physicians.

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### Competing interests
None declared.

### 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
The study complies with the Declaration of Helsinki. As a meta-analysis, the protocol and study did not require the approval from Ethics Committee.

### Provenance and peer review
Not commissioned; externally peer reviewed.

### Data availability statement
Data are available on reasonable request. All data are available from the corresponding author on request.

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