Acetaminophen increases COVID-19 risk: real-time meta analysis of 27 studies

@CovidAnalysis, July 2025, Version 22
https://c19early.org/acemeta.html

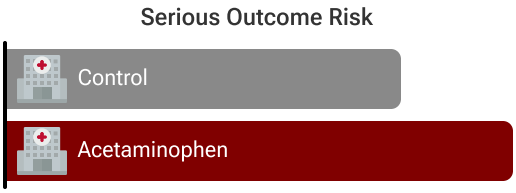
Abstract

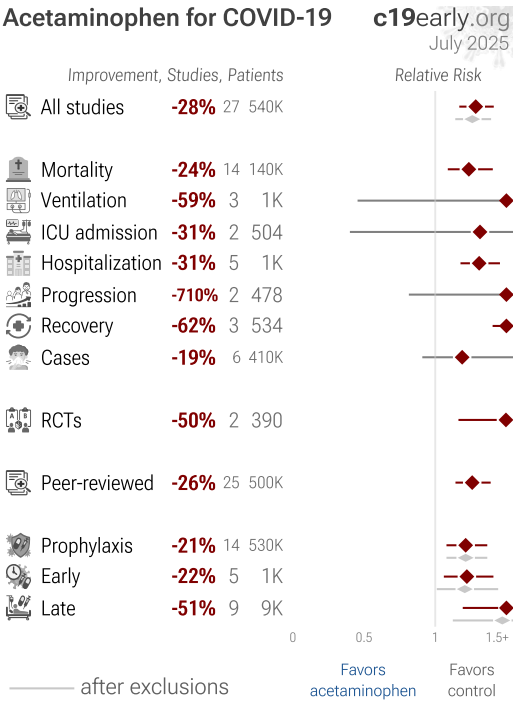
Meta analysis shows 24% [9-40%] higher mortality, and pooled analysis using the most serious outcome reported shows 28% [17-41%] higher risk.

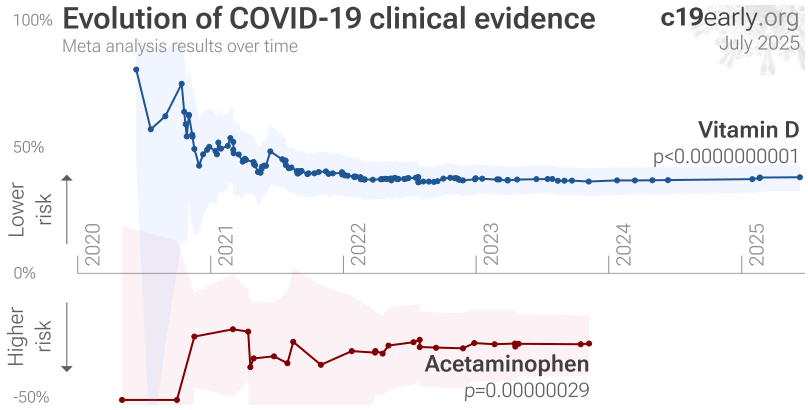
Concerns have been raised over the use of acetaminophen (paracetamol) for COVID-19 [1,2]. Studies show significantly increased risk.

Potential mechanisms of harm include glutathione depletion, fever suppression, liver toxicity, immunosuppression, cytokine disruption, prostaglandin inhibition, COX inhibition, cell/tissue injury, mitochondrial dysfunction, glycine depletion, disruption of redox balance, increased oxidative stress, trace mineral depletion, microbiome alteration, and endocannabinoid system dysfunction.

All data and sources to reproduce this analysis are in the appendix.



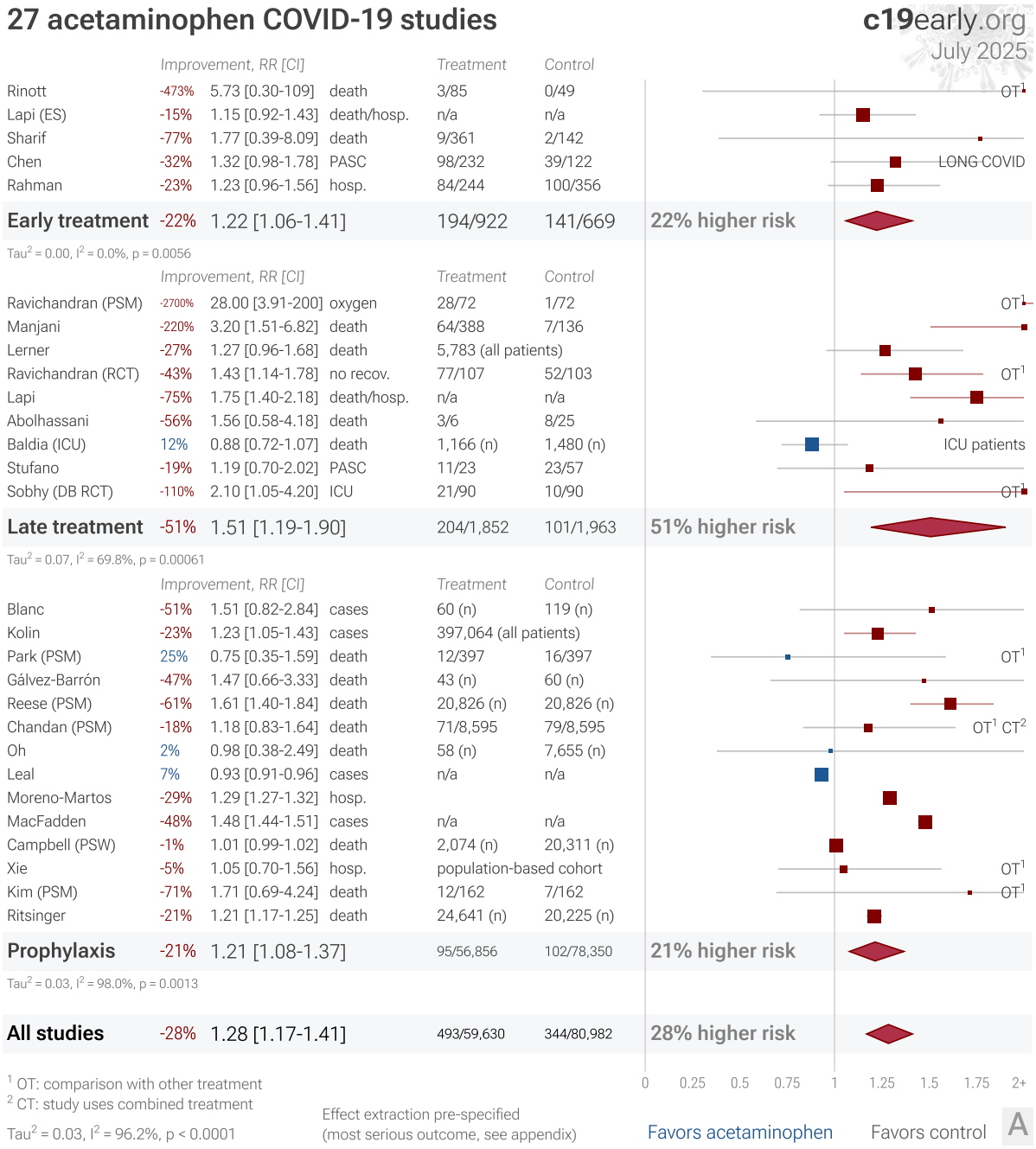




ACETAMINOPHEN FOR COVID-19 — HIGHLIGHTS

2nd treatment shown harmful in November 2020, now with p = 0.00000029 from 27 studies, but still recommended in 103 countries.

Real-time updates and corrections with a consistent protocol for 172 treatments. Outcome specific analysis and combined evidence from all studies including treatment delay, a primary confounding factor.



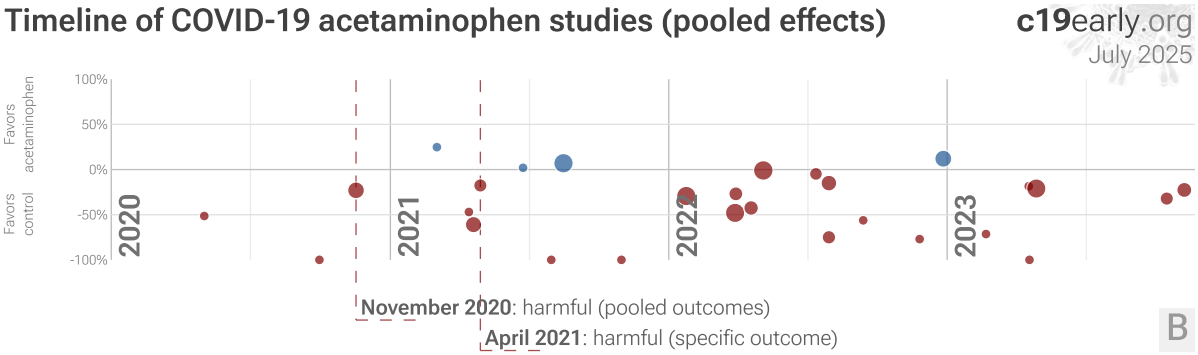


***Figure 1.* A. Random effects meta-analysis.** This plot shows pooled effects, see the specific outcome analyses for individual outcomes. Analysis validating pooled outcomes for COVID-19 can be found below. Effect extraction is pre-specified, using the most serious outcome reported. For details see the appendix. **B. Timeline of results in acetaminophen studies.** The marked dates indicate the time when a harmful effect was identified with statistical significance from ≥3 studies for pooled outcomes and one or more specific outcome. Harm based on specific outcomes was delayed by 5.4 months, compared to using pooled outcomes.

Introduction

Concerns have been raised over the use of acetaminophen (paracetamol) for COVID-19[1,2]. Studies show significantly increased risk. Potential mechanisms of harm include glutathione depletion, fever suppression, liver toxicity, immunosuppression, cytokine disruption, prostaglandin inhibition, COX inhibition, cell/tissue injury, mitochondrial dysfunction, glycine depletion, disruption of redox balance, increased oxidative stress, trace mineral depletion, microbiome alteration, and endocannabinoid system dysfunction.

Other infections

Increased risk with acetaminophen has been shown for rhinovirus[3].

Analysis

We analyze all significant controlled studies of acetaminophen for COVID-19. Search methods, inclusion criteria, effect extraction criteria (more serious outcomes have priority), all individual study data, PRISMA answers, and statistical methods are detailed in Appendix 1. We present random effects meta-analysis results for all studies, studies within each treatment stage, individual outcomes, peer-reviewed studies, Randomized Controlled Trials (RCTs), and higher quality studies.

Treatment timing

Figure 2 shows stages of possible treatment for COVID-19. Prophylaxis refers to regularly taking medication before becoming sick, in order to prevent or minimize infection. Early Treatment refers to treatment immediately or soon after symptoms appear, while Late Treatment refers to more delayed treatment.

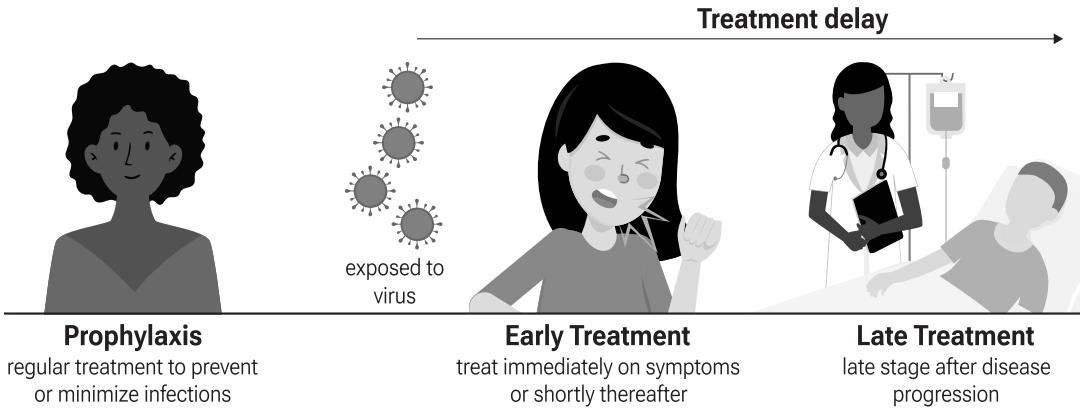


Figure 2. Treatment stages.

Mechanisms of Action

Table 1 shows potential mechanisms by which the treatment of COVID-19 with acetaminophen could be harmful.

Glutathione depletion	Acetaminophen metabolism relies on glutathione, an antioxidant that helps protect cells from damage. Higher or chronic doses of acetaminophen can deplete glutathione levels, which could lead to impaired immune cell function.
Fever suppression	Fever is a natural defense mechanism that helps the body fight off infection. By reducing fever, acetaminophen could potentially prolong infections.
Liver toxicity	Acetaminophen overdose can damage the liver. The liver plays an important role in immune function and inflammation.
Immunosuppression	Some research indicates acetaminophen directly suppresses immune cells such as lymphocytes and macrophages, reducing immune defenses.
Cytokine disruption	Acetaminophen exposure has been found to alter cytokine production, such as reducing IL-6 levels. Cytokines regulate immunity, so this could impair immune responses.
Prostaglandin inhibition	Acetaminophen inhibits prostaglandins, which are signaling molecules that play a role in inflammation and immunity. Reduced prostaglandins could potentially alter immune regulation and make it more difficult for the body to fight off infection.
COX inhibition	Acetaminophen weakly inhibits COX-1/COX-2 enzymes. These generate immune-modulating prostaglandins, so inhibition could alter immunity.
Cell/tissue injury	Acetaminophen is known to cause oxidative injury to cells, even at normal doses. This low-grade damage could potentially trigger inflammatory and immune responses.
Mitochondrial dysfunction	High doses of acetaminophen may impair mitochondrial energy production. Mitochondria play important roles in immune cell activation and function.
Glycine depletion	Conjugating acetaminophen requires glycine, an amino acid that is involved in a number of important biological processes, including immune function. Depletion of glycine could reduce antioxidant production and have immunomodulatory effects.
Disruption of redox balance	Acetaminophen can disrupt the redox balance, which is the balance between antioxidants and free radicals. Free radicals are unstable molecules that can damage cells. If the redox balance is disrupted, it could lead to increased inflammation and impaired immune cell function.
Increased oxidative stress	Beyond glutathione depletion, acetaminophen can increase reactive oxygen species and oxidative stress. Oxidative stress can damage cells and trigger inflammation.
Trace mineral depletion	Acetaminophen increases urinary excretion of trace minerals involved in immunity like zinc, selenium, and manganese.
Microbiome alteration	Acetaminophen exposure might alter the intestinal microbiota, which is the community of bacteria that live in the gut. The intestinal microbiota plays an important role in immune function, so changes to the microbiota could make it more difficult for the body to fight off infection.
Endocannabinoid system dysfunction	Acetaminophen may disrupt endocannabinoid signaling, which helps regulate immune function. This could lead to improper immune responses.

Table 1. **Mechanisms of action for potential harmful effects with acetaminophen treatment.**

Beneficial Effects of Fever

Fever is an important component of the acute response to coronavirus infection[4]. The evolutionary conservation of fever for over 600 million years supports a survival benefit[5]. Viral particle sensing occurs via pattern recognition receptors, such as toll-like receptors, triggering release of endogenous pyrogens such as interleukin-1. These cytokines induce thermoregulatory centers in the hypothalamus to elevate core temperature setpoints above normal homeostasis. The resulting fever enhances multiple aspects of the innate and adaptive immune systems[5], and creates a suboptimal internal environment that impairs SARS-CoV-2 enzyme function and replication. *In Vitro* studies demonstrate reduced viral output at sustained febrile temperatures of 38-39°C compared to basal 37°C conditions. Fever also correlates clinically with heightened interferon-γ, interleukin-6, lymphocyte activation, and antibody production critical for viral clearance.

Los et al. showed that higher temperature enhanced the expression of antiviral genes and reduced SARS-CoV-2 replication in Calu-3 and Caco-2 cells. An in vivo hamster model showed that higher body temperature at the time of infection correlated with lower viral loads.

Zhou et al. showed that SARS-CoV-2 patients with higher fever had lower viral load. Molecular dynamics simulations, surface plasmon resonance experiments, and pseudovirus cell entry assays showed decreased SARS-CoV-2 binding affinity to the human ACE2 receptor at higher temperature (40°C vs. 37°C).

Downing et al. induced hyperthermia (fever-like temperatures) in human volunteers by immersing them in warm water baths. They found that lymphocytes isolated from individuals with core body temperatures elevated to 39°C produced up to 10 times more interferon-γ, as shown in Figure 3. They also found an increase in suppressor/cytotoxic T cells and natural killer cells. The threshold of 39°C suggests relevance to fever, and the results suggest fever may play a role in boosting antiviral and immunoregulatory activities.

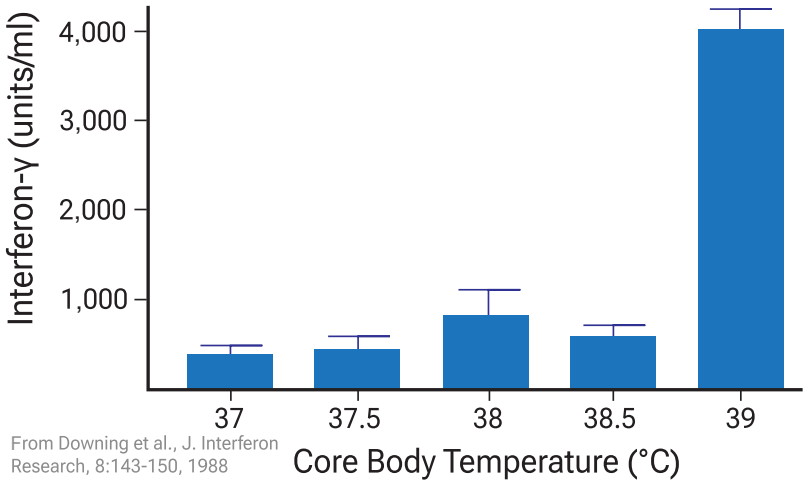


Figure 3. **A 10 fold increase in interferon-γ production was seen when core body temperature reached 39°C, from** *Downing et al.*

Herder et al. perform *in vitro* analysis with a 3D respiratory epithelial model using cells from human donors. Authors showed that elevated temperature (39-40°C) restricts SARS-CoV-2 infection and replication independently of interferon-mediated antiviral defenses. Authors found SARS-CoV-2 can still enter respiratory cells at 40°C but viral transcription and replication are inhibited, limiting the production of infectious virus. This temperature-dependent restriction correlates with altered host gene expression related to antiviral immunity and epigenetic regulation. The results suggest that febrile temperature ranges may confer protection to respiratory tissues by restricting SARS-CoV-2 propagation.

Dominguez-Nicolas et al. induced localized hyperthermia using LF-ThMS applied to the dorsal thorax (up to 44°C externally), resulting in significantly increased peripheral oxygen saturation (SpO_2) levels in COVID-19 patients, as shown in Figure 4.

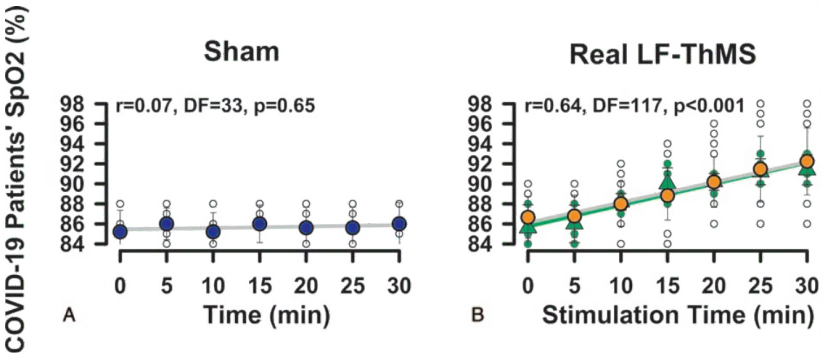


Figure 4. Rapidly increasing SpO_2 in COVID-19 patients with localized thoracic hyperthermia, from *Dominguez-Nicolas et al.*

Ramirez et al. compared COVID-19 mortality in Finland and Estonia, where sauna use is part of the culture and is typically practiced at least once a week, with the rest of Europe. Authors found significantly lower mortality with sauna culture, and suggest this may be due to the beneficial effects of hydrothermotherapy.

Ruble et al. compared army hospital vs. sanitarium treatment for the 1918 Spanish influenza, showing lower progression to pneumonia and lower mortality with sanitarium treatment, which involves hydrothermotherapy, sunlight, and fresh air.

Stewart reports on the use of diathermy in the treatment of pneumonia in 1926, with case reports from several physicians covering over 300 patients. Author reports that diathermy had consistent positive effects without significant adverse events, resulted in about half the mortality of the control group, significantly alleviated symptoms such as dyspnea, pain, and cardiac strain, and improved sleep and reduced respiratory rates.

Recent atom-level work strengthens the mechanistic case for fever-mediated viral attenuation. *Xie et al.* performed 200-ns equilibration followed by replicate 100-ns all-atom MD simulations of the spike RBD–ACE2 peptidase complex across physiologic-to-febrile temperatures. At 315 K the interface lost ~1 hydrogen bond, solvent exposure grew by ~4 Å², dissociation probability tripled, and MM-PBSA binding free energy became ≈59 kcal mol-¹ less favorable, driven by heat-induced straightening of the ACE2 α1-helix and withdrawal of the β3β4 hairpin that jointly destabilise the two anchor regions. Mild-cool conditions (305 K) had the opposite effect, α1-helix curvature tightened the interface, dissociation dropped eight-fold, and binding free energy became ~21 kcal mol-¹ more favorable. These thermodynamic shifts directly support febrile-range hyperthermia as a barrier to initial viral attachment.

In summary, fever is a key component of the response to infection. Fever enhances immune cell performance, induces cellular stress on pathogens, and may act synergistically with other stressors like iron deprivation. While results show beneficial effects of fever, it is not universally beneficial. Extreme or prolonged cases may be harmful. Fever may be more detrimental for individuals with lower tolerance for the increased metabolic demands.

Fever may also reduce transmissibility. Fever helps clear infection faster by enhancing immune responses and applying cellular stress to pathogens. Faster clearance gives the pathogen less time to amplify within the host to reach contagious levels. Fever may also apply evolutionary pressure resulting in sacrificing replicative fitness at normal temperatures, minimizing infection in other hosts. Further, fever promotes reduced activity, minimizing the opportunity for transmission.

The beneficial effects of fever suggest potential harm from fever-reducing medications in terms of an increased risk of poor outcomes and increased transmission. However, these may be offset by other effects of specific medications, including anticoagulant, anti-inflammatory, or antiviral effects.

Results

Table 2 summarizes the results for all stages combined, for Randomized Controlled Trials, for peer-reviewed studies, after exclusions, and for specific outcomes. Table 3 shows results by treatment stage. Figure 5 plots individual results by treatment stage. Figure 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17 show forest plots for random effects meta-analysis of all studies with pooled effects, mortality results, ventilation, ICU admission, hospitalization, progression, recovery, cases, viral clearance, peer reviewed studies, non-symptomatic vs. symptomatic results, and long COVID.

	Relative Risk	Studies	Patients
All studies	1.28 [1.17-1.41] ****	27	540K
After exclusions	1.26 [1.14-1.39] ****	23	540K
Peer-reviewed	1.26 [1.14-1.39] ****	25	500K
RCTs	1.50 [1.16-1.93] **	2	390
Mortality	1.24 [1.09-1.40] **	14	140K
Ventilation	1.59 [0.45-5.54]	3	1,642
ICU admission	1.31 [0.40-4.31]	2	504
Hospitalization	1.31 [1.18-1.45] ****	5	1,304
Recovery	1.62 [1.40-1.87] ****	3	534
Cases	1.19 [0.91-1.56]	6	410K

Table 2. **Random effects meta-analysis for all stages combined, for Randomized Controlled Trials, for peer-reviewed studies, after exclusions, and for specific outcomes.** Results show the relative risk with treatment and the 95% confidence interval. * $p<0.05$ ** $p<0.01$ *** $p<0.001$ **** $p<0.0001$.

	Early treatment	Late treatment	Prophylaxis
All studies	1.22 [1.06-1.41] **	1.51 [1.19-1.90] ***	1.21 [1.08-1.37] **
After exclusions	1.21 [1.01-1.44] *	1.47 [1.12-1.93] **	1.21 [1.08-1.37] **
Peer-reviewed	1.22 [1.06-1.41] **	1.51 [1.19-1.90] ***	1.17 [1.03-1.32] *
RCTs		1.50 [1.16-1.93] **	
Mortality	2.27 [0.59-8.75]	1.36 [0.91-2.04]	1.21 [1.05-1.41] *
Ventilation		5.34 [1.98-14.45] ***	0.87 [0.42-1.83]
ICU admission		2.10 [1.05-4.20] *	0.60 [0.15-2.47]
Hospitalization	1.23 [0.96-1.56]	1.59 [1.09-2.30] *	1.29 [1.20-1.37] ****
Recovery		1.62 [1.40-1.87] ****	
Cases			1.19 [0.91-1.56]

Table 3. **Random effects meta-analysis results by treatment stage.** Results show the relative risk with treatment and the 95% confidence interval. * $p<0.05$ ** $p<0.01$ *** $p<0.001$ **** $p<0.0001$.

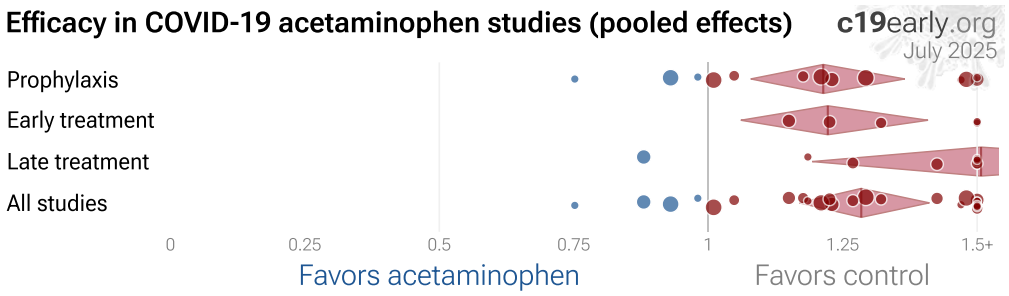


Figure 5. **Scatter plot showing the most serious outcome in all studies, and for studies within each stage.** Diamonds shows the results of random effects meta-analysis.

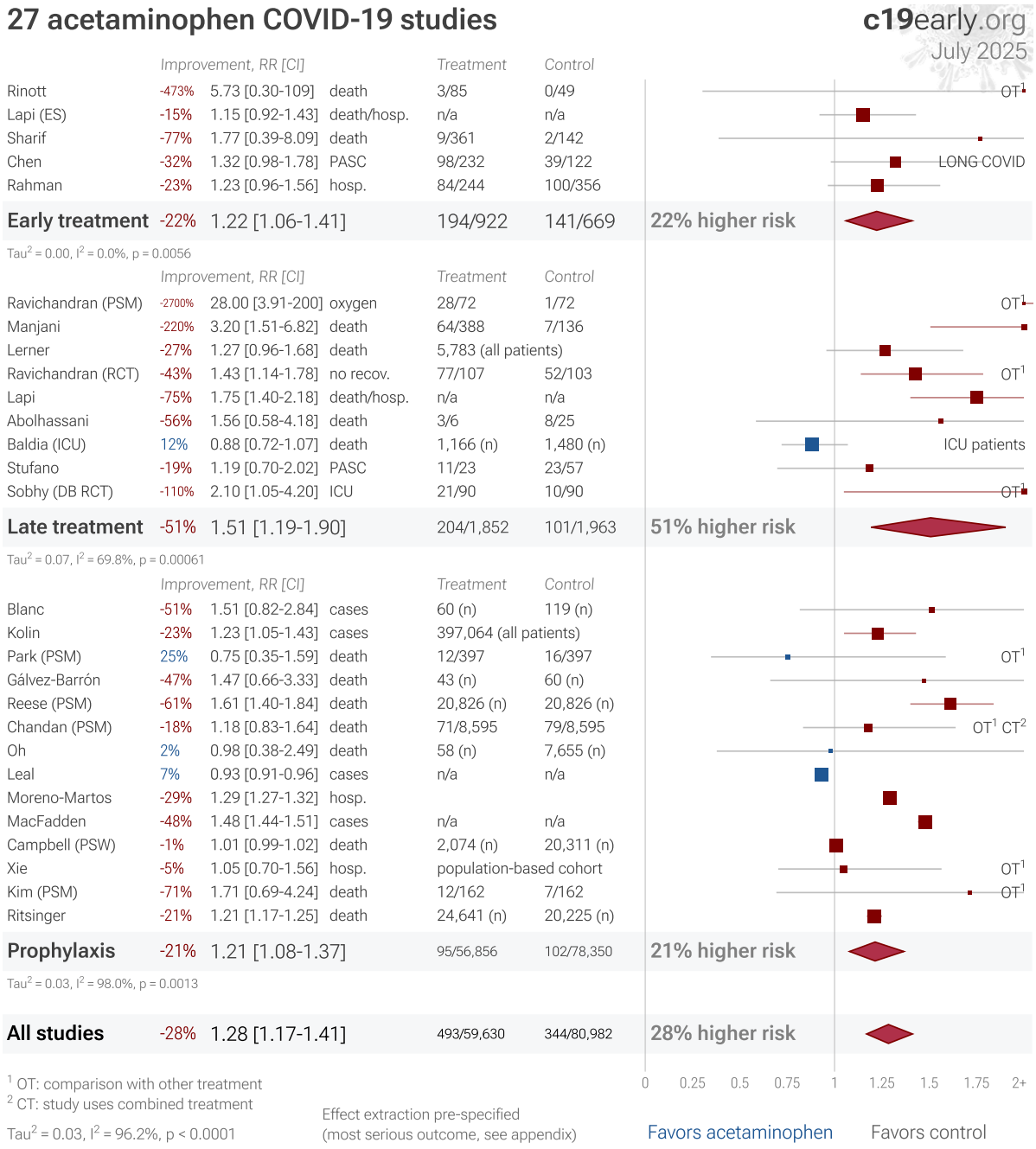


Figure 6. **Random effects meta-analysis for all studies.** This plot shows pooled effects, see the specific outcome analyses for individual outcomes. Analysis validating pooled outcomes for COVID-19 can be found below. Effect extraction is pre-specified, using the most serious outcome reported. For details see the appendix.

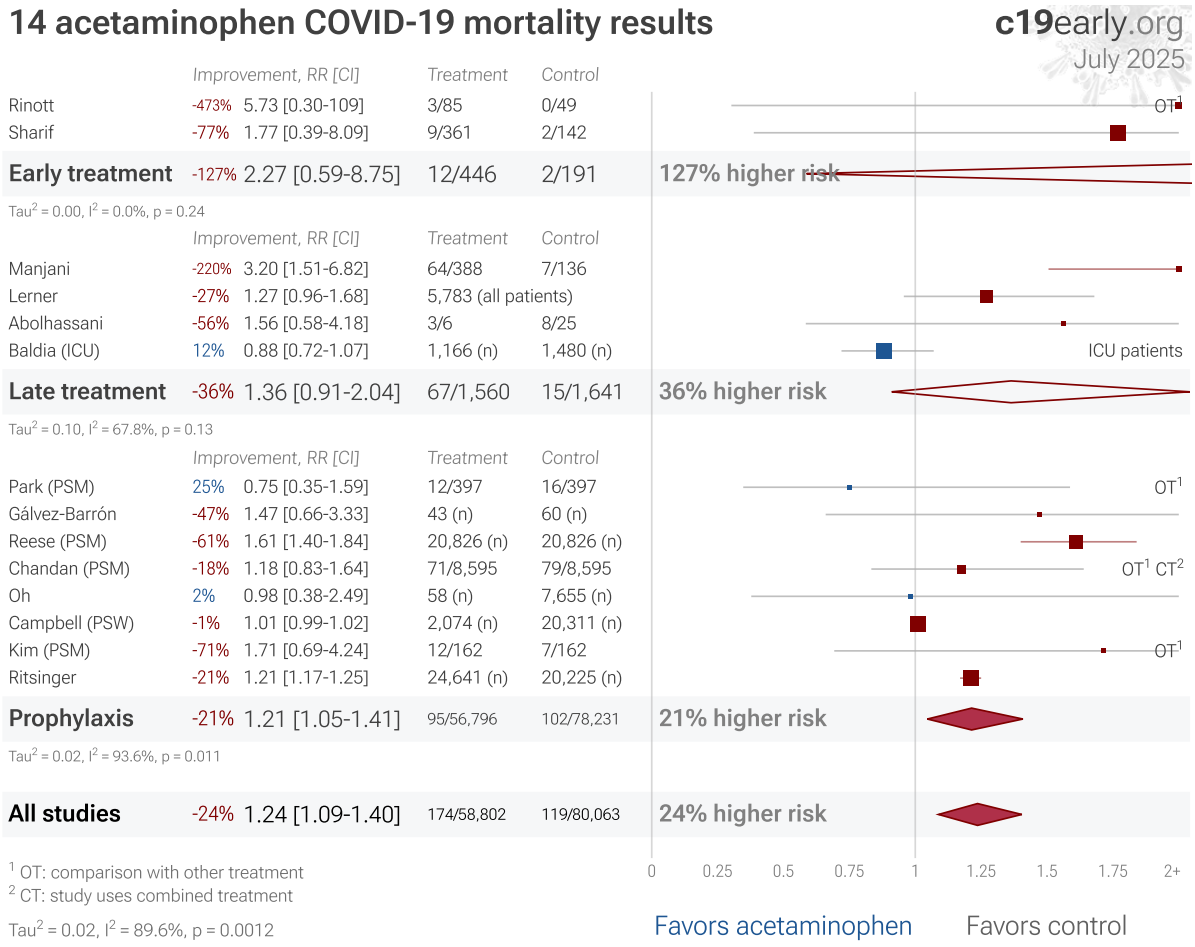


Figure 7. Random effects meta-analysis for mortality results.

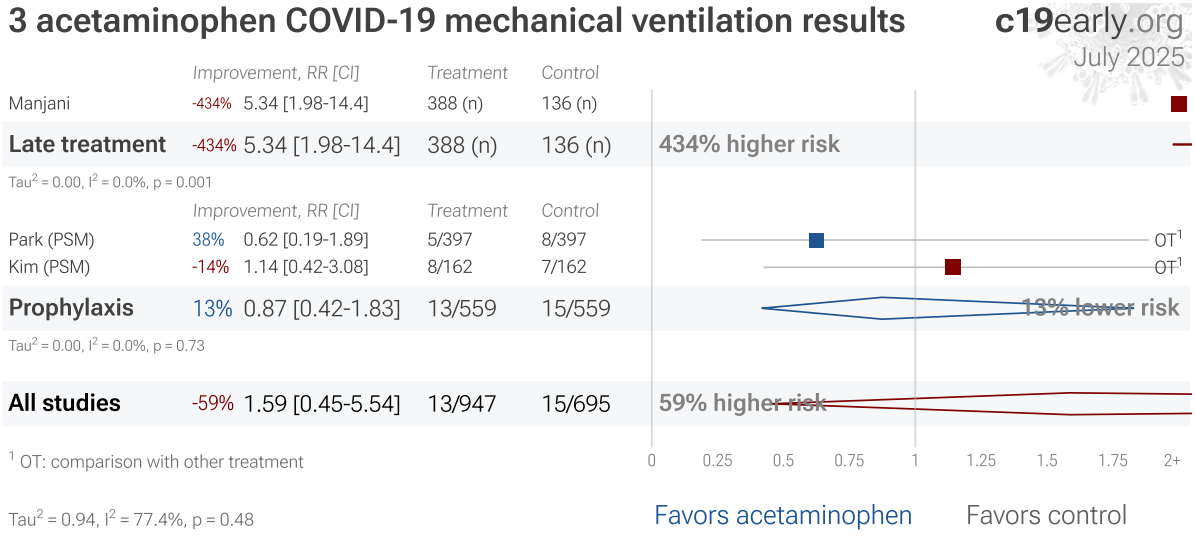


Figure 8. Random effects meta-analysis for ventilation.

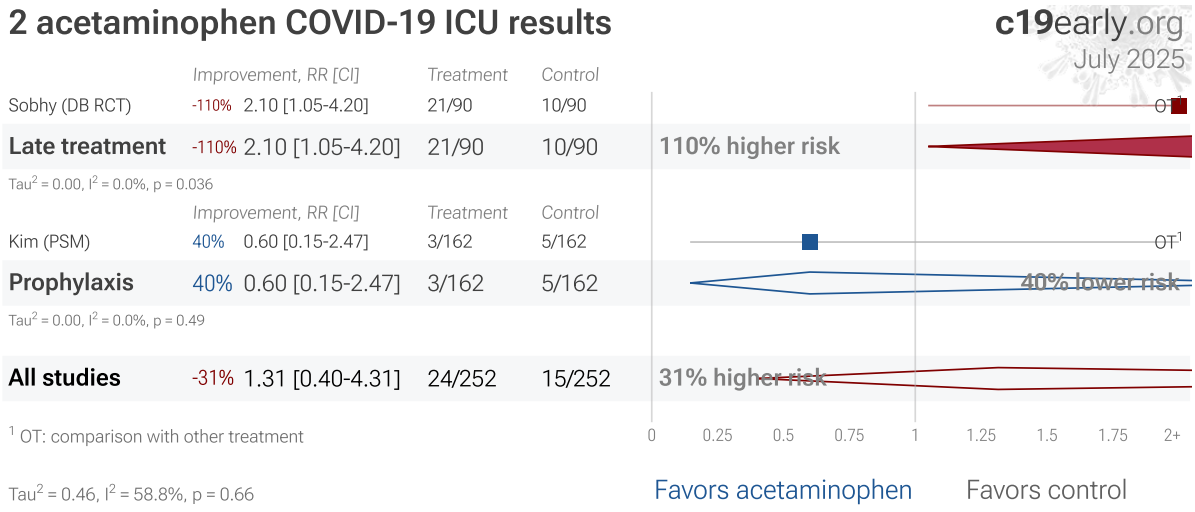


Figure 9. Random effects meta-analysis for ICU admission.

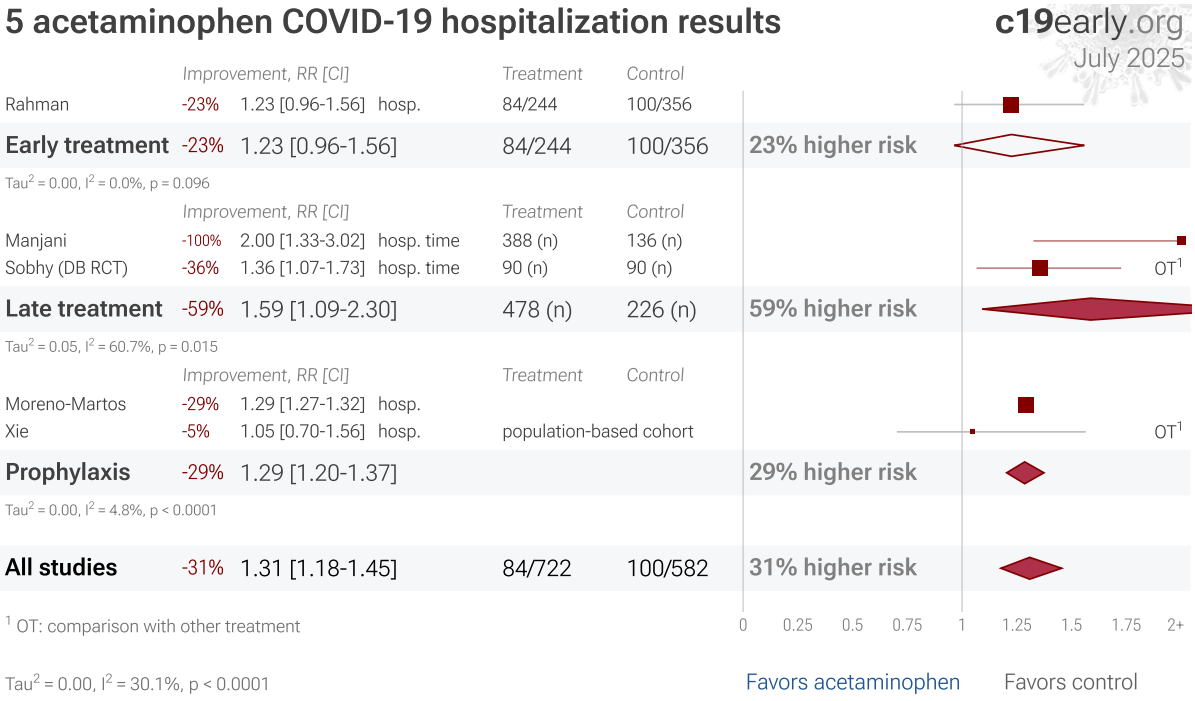


Figure 10. Random effects meta-analysis for hospitalization.

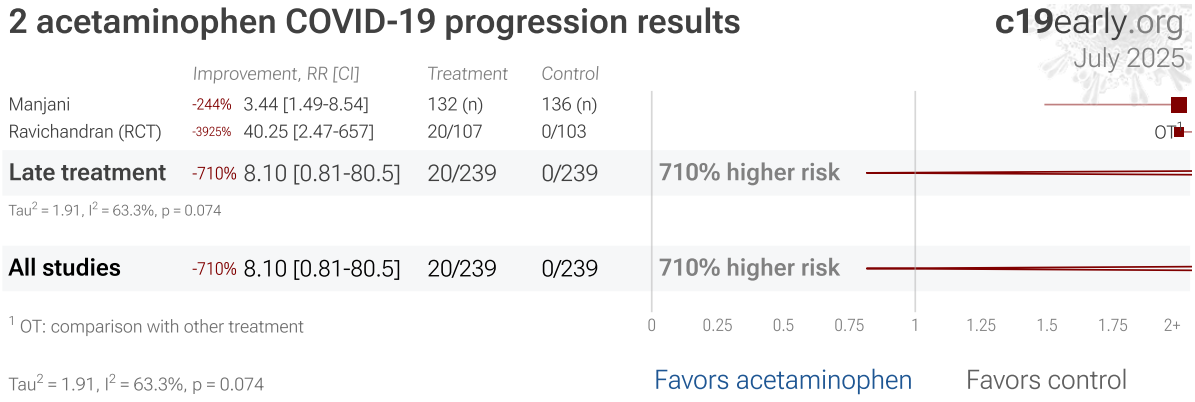


Figure 11. Random effects meta-analysis for progression.

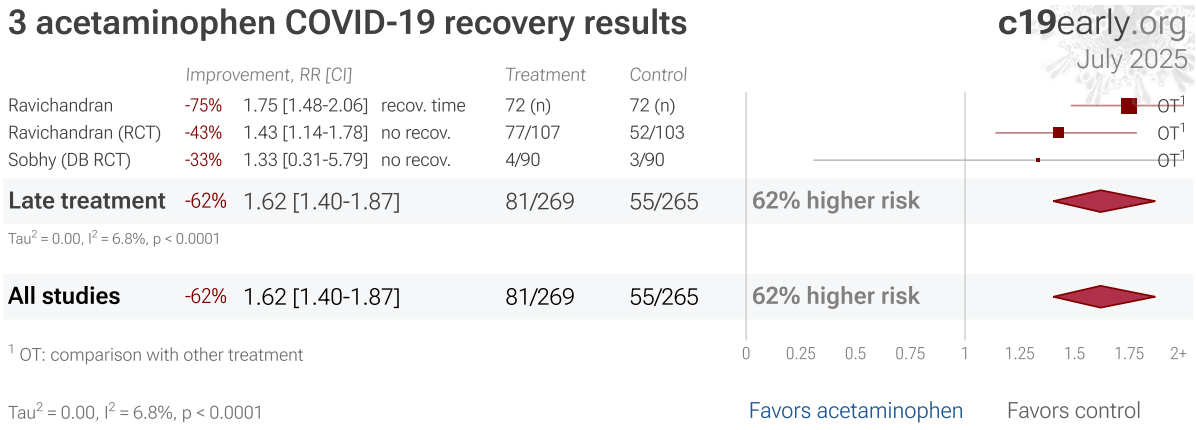


Figure 12. Random effects meta-analysis for recovery.

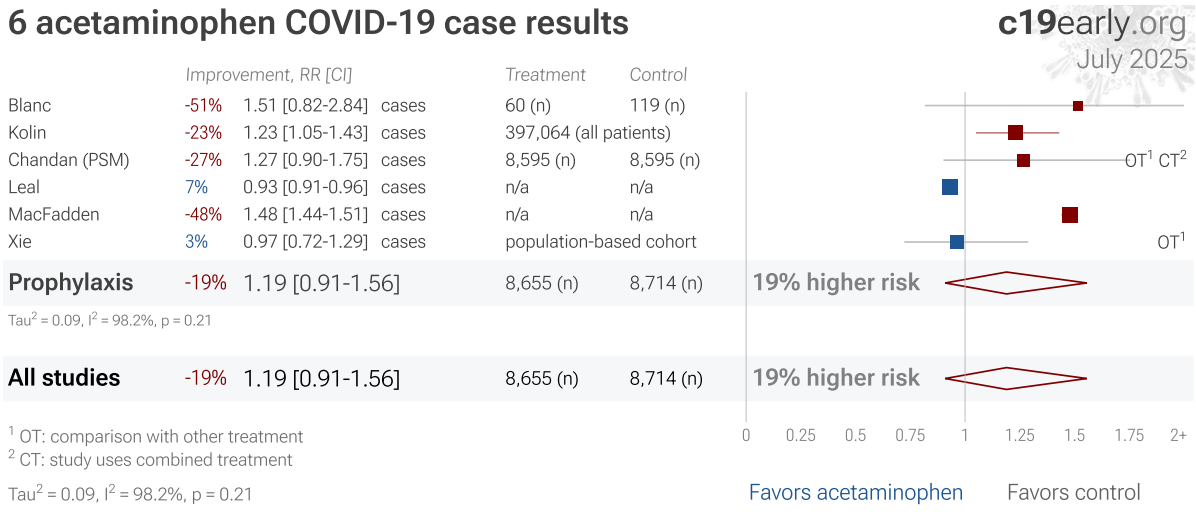


Figure 13. Random effects meta-analysis for cases.

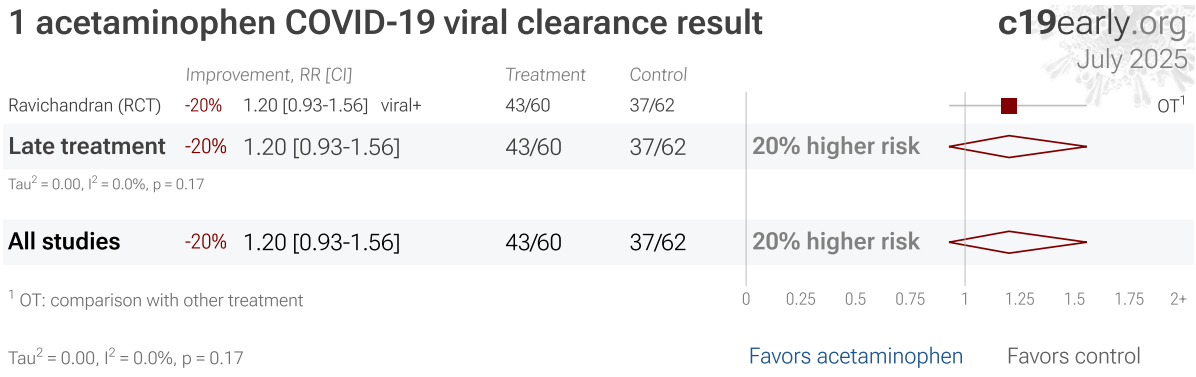


Figure 14. Random effects meta-analysis for viral clearance.

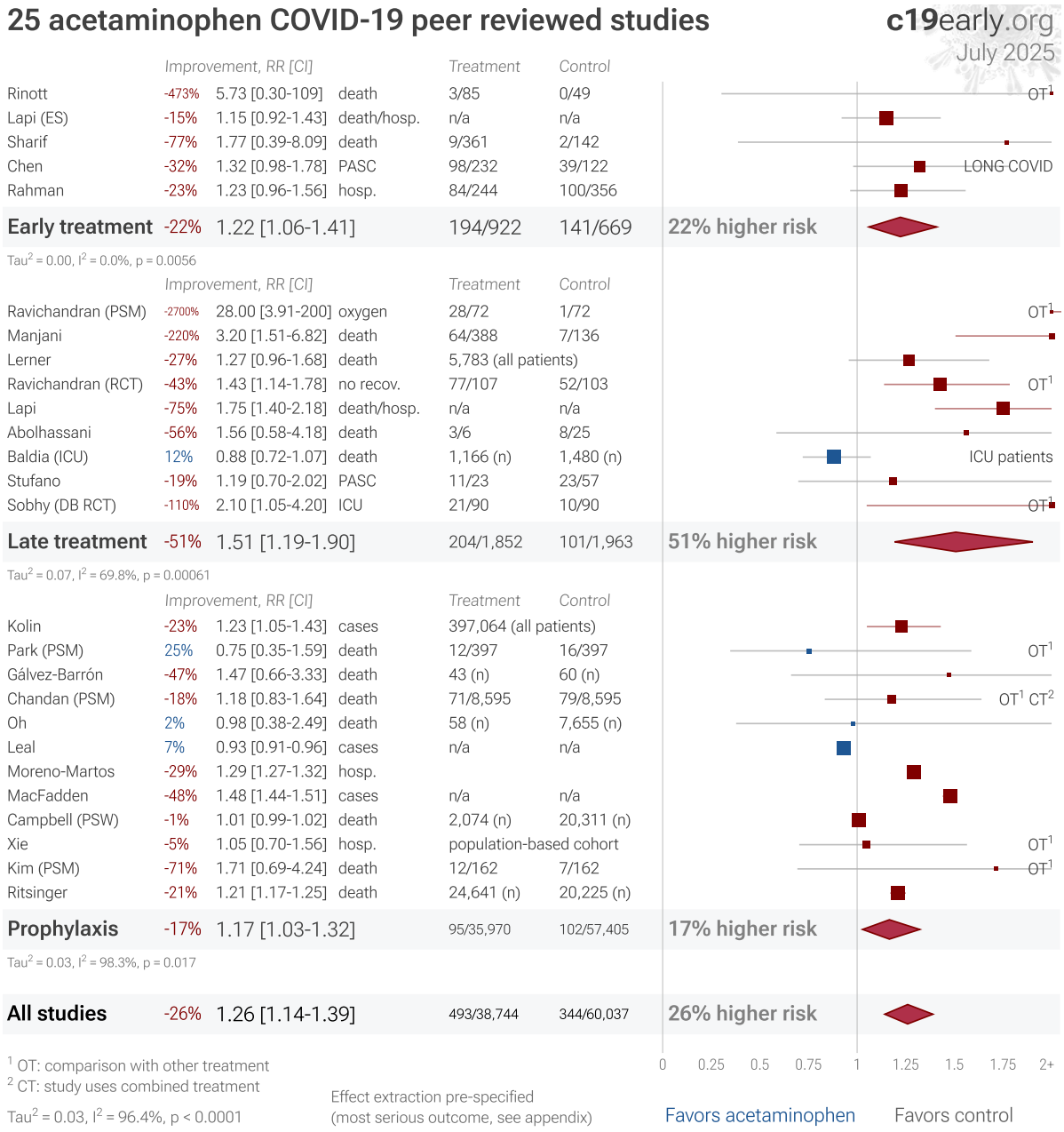


Figure 15. **Random effects meta-analysis for peer reviewed studies.** Effect extraction is pre-specified, using the most serious outcome reported, see the appendix for details. Analysis validating pooled outcomes for COVID-19 can be found below. *Zeraatkar et al.* analyze 356 COVID-19 trials, finding no significant evidence that preprint results are inconsistent with peer-reviewed studies. They also show extremely long peer-review delays, with a median of 6 months to journal publication. A six month delay was equivalent to around 1.5 million deaths during the first two years of the pandemic. Authors recommend using preprint evidence, with appropriate checks for potential falsified data, which provides higher certainty much earlier. *Davidson et al.* also showed no important difference between meta analysis results of preprints and peer-reviewed publications for COVID-19, based on 37 meta analyses including 114 trials.

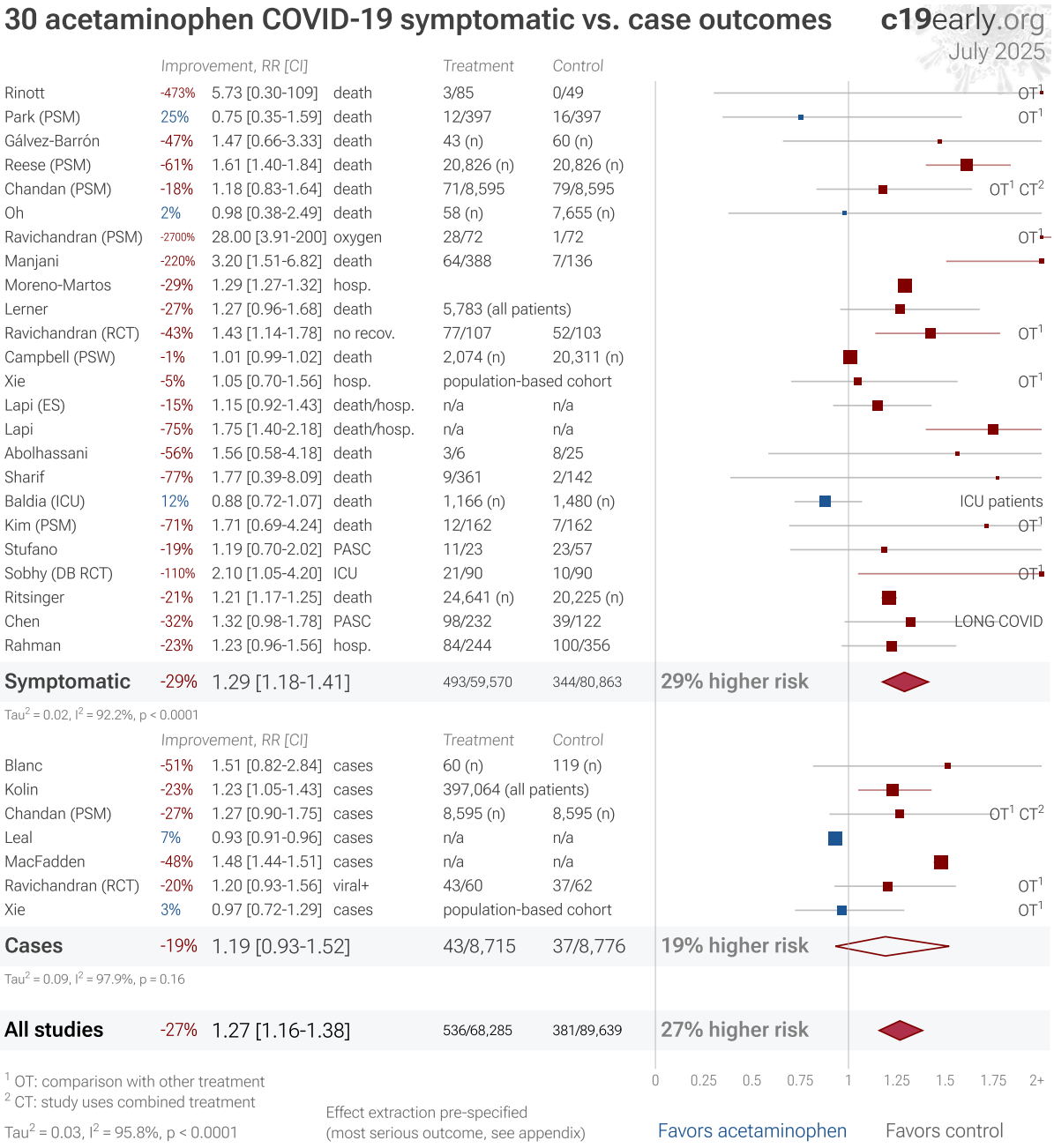


Figure 16. **Random effects meta-analysis for non-symptomatic vs. symptomatic results.** Effect extraction is pre-specified, using the most serious outcome reported, see the appendix for details. Analysis validating pooled outcomes for COVID-19 can be found below.

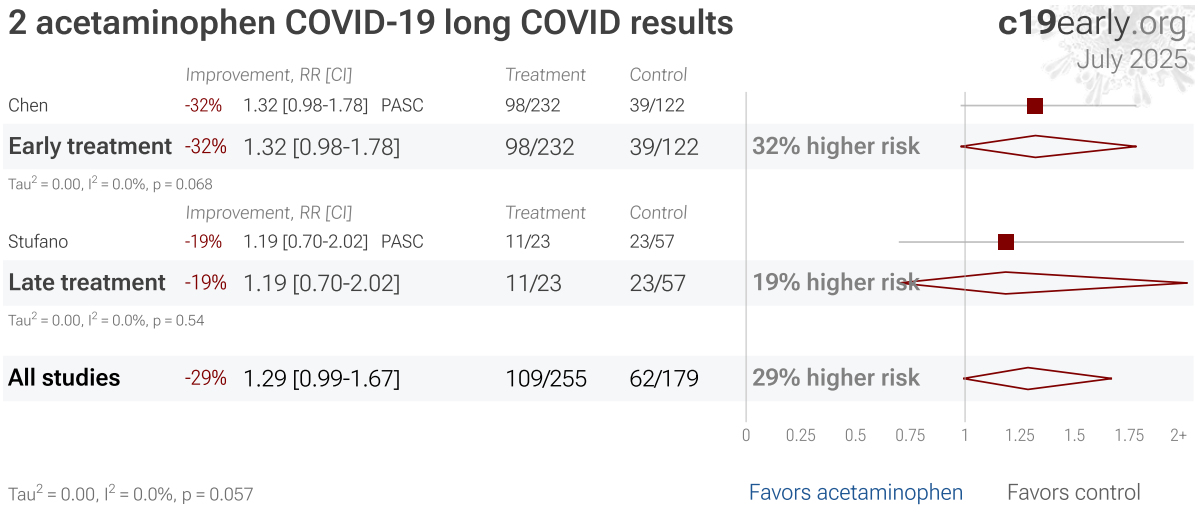


Figure 17. **Random effects meta-analysis for long COVID.** Effect extraction is pre-specified, using the most serious outcome reported, see the appendix for details. Analysis validating pooled outcomes for COVID-19 can be found below.

Randomized Controlled Trials (RCTs)

Figure 18 shows a comparison of results for RCTs and observational studies. Figure 19 shows a forest plot for random effects meta-analysis of all Randomized Controlled Trials. RCT results are included in Table 2 and Table 3.

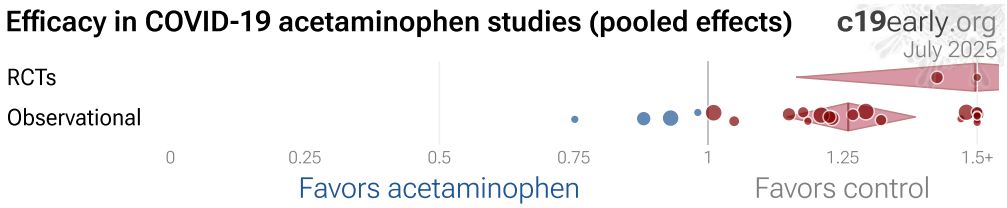


Figure 18. **Results for RCTs and observational studies.**

RCTs have many potential biases

RCTs help to make study groups more similar and can provide a higher level of evidence, however they are subject to many biases [17], and analysis of double-blind RCTs has identified extreme levels of bias [18]. For COVID-19, the overhead may delay treatment, dramatically compromising efficacy; they may encourage monotherapy for simplicity at the cost of efficacy which may rely on combined or synergistic effects; the participants that sign up may not reflect real world usage or the population that benefits most in terms of age, comorbidities, severity of illness, or other factors; standard of care may be compromised and unable to evolve quickly based on emerging research for new diseases; errors may be made in randomization and medication delivery; and investigators may have hidden agendas or vested interests influencing design, operation, analysis, reporting, and the potential for fraud. All of these biases have been observed with COVID-19 RCTs. There is no guarantee that a specific RCT provides a higher level of evidence.

Conflicts of interest for COVID-19 RCTs

RCTs are expensive and many RCTs are funded by pharmaceutical companies or interests closely aligned with pharmaceutical companies. For COVID-19, this creates an incentive to show efficacy for patented commercial products, and an incentive to show a lack of efficacy for inexpensive treatments. The bias is expected to be significant, for example *Als-Nielsen et al.* analyzed 370 RCTs from Cochrane reviews, showing that trials funded by for-profit organizations were 5 times more likely to recommend the experimental drug compared with those funded by nonprofit organizations. For COVID-19, some major philanthropic organizations are largely funded by investments with extreme conflicts of interest for and against specific COVID-19 interventions.

RCTs for novel acute diseases requiring rapid treatment

High quality RCTs for novel acute diseases are more challenging, with increased ethical issues due to the urgency of treatment, increased risk due to enrollment delays, and more difficult design with a rapidly evolving evidence base. For COVID-19, the most common site of initial infection is the upper respiratory tract. Immediate treatment is likely to be most successful and may prevent or slow progression to other parts of the body. For a non-prophylaxis RCT, it makes sense to provide treatment in advance and instruct patients to use it immediately on symptoms, just as some governments have done by providing medication kits in advance. Unfortunately, no RCTs have been done in this way. Every treatment RCT to date involves delayed treatment. Among the 172 treatments we have analyzed, 67% of RCTs involve very late treatment 5+ days after onset. No non-prophylaxis COVID-19 RCTs match the potential real-world use of early treatments. They may more accurately represent results for treatments that require visiting a medical facility, e.g., those requiring intravenous administration.

RCT bias for widely available treatments

RCTs have a bias against finding an effect for interventions that are widely available — patients that believe they need the intervention are more likely to decline participation and take the intervention. RCTs for acetaminophen are more likely to enroll low-risk participants that do not need treatment to recover, making the results less applicable to clinical practice. This bias is likely to be greater for widely known treatments, and may be greater when the risk of a serious outcome is overstated. This bias does not apply to the typical pharmaceutical trial of a new drug that is otherwise unavailable.

Using all studies identifies efficacy 8+ months faster (9+ months for low-cost treatments)

Currently, 55 of the treatments we analyze show statistically significant efficacy or harm, defined as ≥10% decreased risk or >0% increased risk from ≥3 studies. Of these, 58% have been confirmed in RCTs, with a mean delay of 7.7 months (64% with 8.9 months delay for low-cost treatments). The remaining treatments either have no RCTs, or the point estimate is consistent.

Summary

We need to evaluate each trial on its own merits. RCTs for a given medication and disease may be more reliable, however they may also be less reliable. For off-patent medications, very high conflict of interest trials may be more likely to be RCTs, and more likely to be large trials that dominate meta analyses.

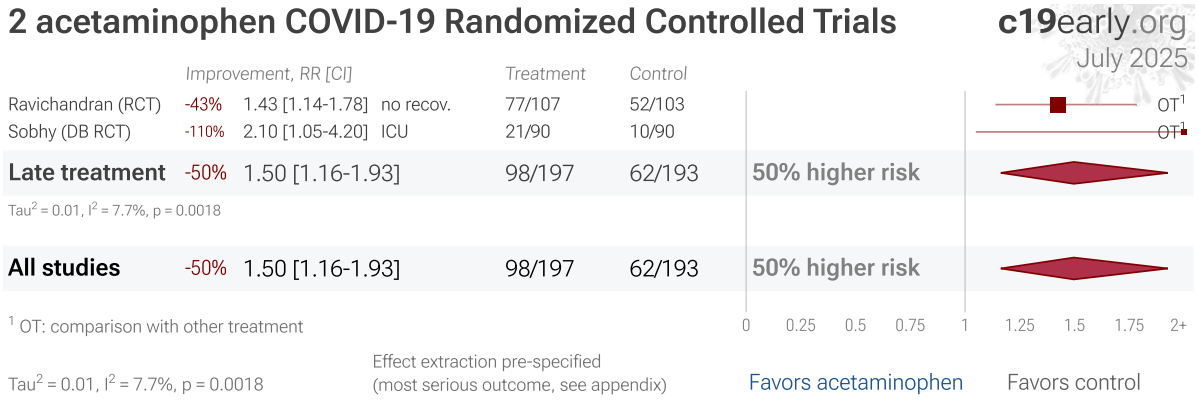


Figure 19. **Random effects meta-analysis for all Randomized Controlled Trials.** This plot shows pooled effects, see the specific outcome analyses for individual outcomes. Analysis validating pooled outcomes for COVID-19 can be found below. Effect extraction is pre-specified, using the most serious outcome reported. For details see the appendix.

Exclusions

To avoid bias in the selection of studies, we analyze all non-retracted studies. Here we show the results after excluding studies with major issues likely to alter results, non-standard studies, and studies where very minimal detail is currently available. Our bias evaluation is based on analysis of each study and identifying when there is a significant chance that limitations will substantially change the outcome of the study. We believe this can be more valuable than checklist-based approaches such as Cochrane GRADE, which can be easily influenced by potential bias, may ignore or underemphasize serious issues not captured in the checklists, and may overemphasize issues unlikely to alter outcomes in specific cases (for example certain specifics of randomization with a very large effect size and well-matched baseline characteristics).

The studies excluded are as below. Figure 20 shows a forest plot for random effects meta-analysis of all studies after exclusions.

Lapi, substantial unadjusted confounding by indication likely.

Rahman, unadjusted results with no group details; significant unadjusted confounding possible.

Rinott, unadjusted differences between groups.

Sharif, unadjusted results with no group details.

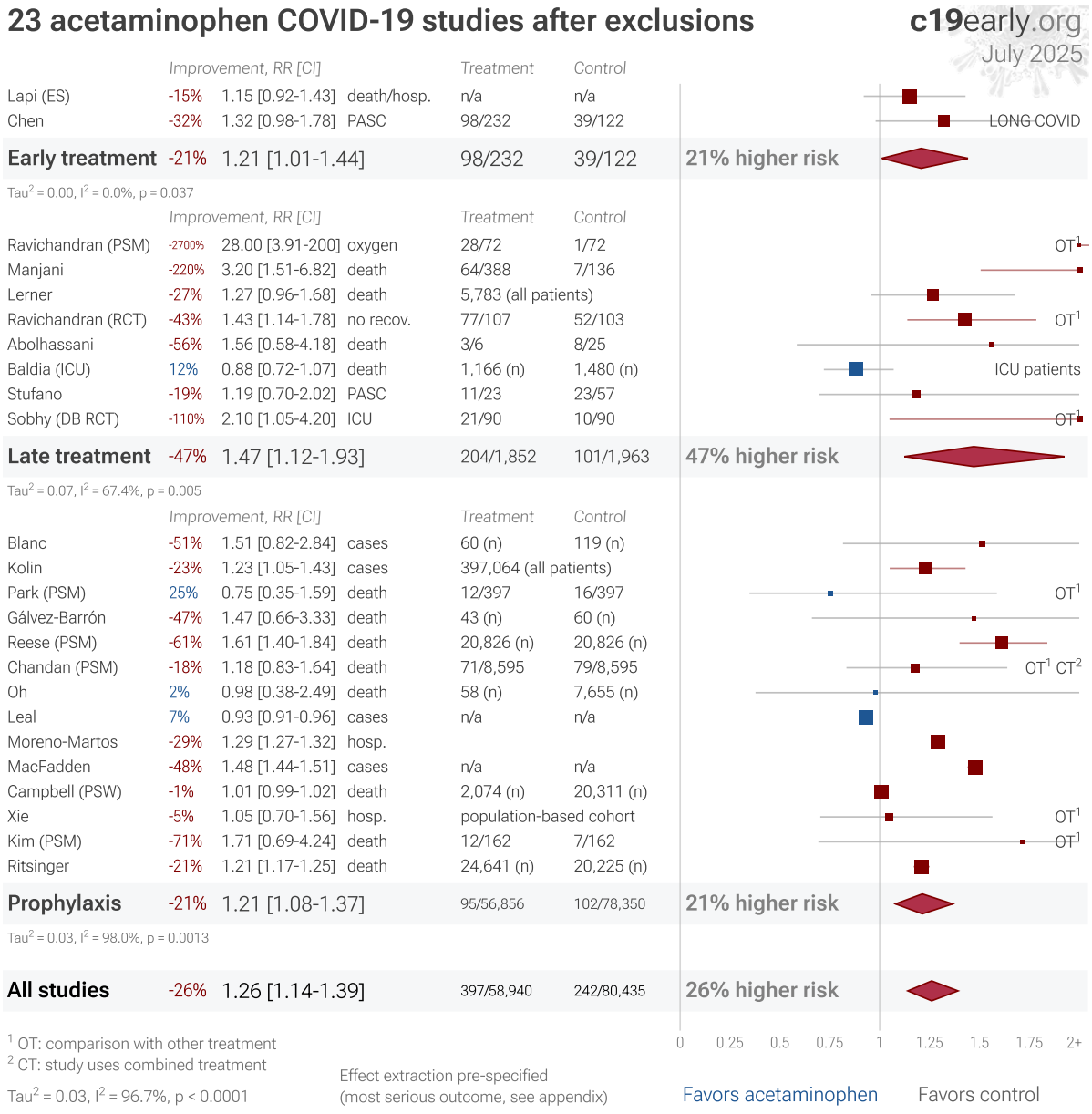


Figure 20. **Random effects meta-analysis for all studies after exclusions.** This plot shows pooled effects, see the specific outcome analyses for individual outcomes. Analysis validating pooled outcomes for COVID-19 can be found below. Effect extraction is pre-specified, using the most serious outcome reported. For details see the appendix.

Heterogeneity

Heterogeneity in COVID-19 studies arises from many factors including:

Treatment delay

The time between infection or the onset of symptoms and treatment may critically affect how well a treatment works. For example an antiviral may be very effective when used early but may not be effective in late stage disease, and may even be harmful. Oseltamivir, for example, is generally only considered effective for influenza when used within 0-36 or 0-48 hours[24,25]. Baloxavir marboxil studies for influenza also show that treatment delay is critical — *Ikematsu et al.* report an 86% reduction in cases for post-exposure prophylaxis, *Hayden et al.* show a 33 hour reduction in the time to alleviation of symptoms for treatment within 24 hours and a reduction of 13 hours for treatment within 24-48 hours, and *Kumar et al.* report only 2.5 hours improvement for inpatient treatment.

Treatment delay	Result
Post-exposure prophylaxis	86% fewer cases[26]
<24 hours	-33 hours symptoms[27]
24-48 hours	-13 hours symptoms[27]
Inpatients	-2.5 hours to improvement[28]

Table 4. **Studies of baloxavir marboxil for influenza show that early treatment is more effective.**

Figure 21 shows a mixed-effects meta-regression for efficacy as a function of treatment delay in COVID-19 studies from 172 treatments, showing that efficacy declines rapidly with treatment delay. Early treatment is critical for COVID-19.

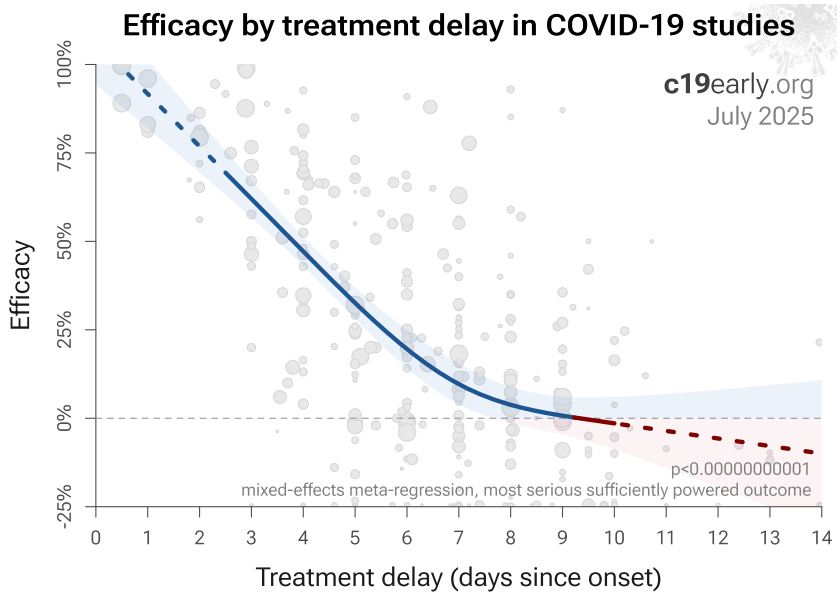


Figure 21. **Early treatment is more effective.** Meta-regression showing efficacy as a function of treatment delay in COVID-19 studies from 172 treatments.

Patient demographics

Details of the patient population including age and comorbidities may critically affect how well a treatment works. For example, many COVID-19 studies with relatively young low-comorbidity patients show all patients recovering quickly with or without treatment. In such cases, there is little room for an effective treatment to improve results, for example as in *López-Medina et al.*

SARS-CoV-2 variants

Efficacy may depend critically on the distribution of SARS-CoV-2 variants encountered by patients. Risk varies significantly across variants[30], for example the Gamma variant shows significantly different characteristics[31-34]. Different mechanisms of action may be more or less effective depending on variants, for example the degree to which TMPRSS2 contributes to viral entry can differ across variants[35,36].

Treatment regimen

Effectiveness may depend strongly on the dosage and treatment regimen.

Medication quality

The quality of medications may vary significantly between manufacturers and production batches, which may significantly affect efficacy and safety. *Williams et al.* analyze ivermectin from 11 different sources, showing highly variable antiparasitic efficacy across different manufacturers. *Xu et al.* analyze a treatment from two different manufacturers, showing 9 different impurities, with significantly different concentrations for each manufacturer.

Other treatments

The use of other treatments may significantly affect outcomes, including supplements, other medications, or other interventions such as prone positioning. Treatments may be synergistic[39-55], therefore efficacy may depend strongly on combined treatments.

Effect measured

Across all studies there is a strong association between different outcomes, for example improved recovery is strongly associated with lower mortality. However, efficacy may differ depending on the effect measured, for example a treatment may be more effective against secondary complications and have minimal effect on viral clearance.

Meta analysis

The distribution of studies will alter the outcome of a meta analysis. Consider a simplified example where everything is equal except for the treatment delay, and effectiveness decreases to zero or below with increasing delay. If there are many studies using very late treatment, the outcome may be negative, even though early treatment is very effective. All meta analyses combine heterogeneous studies, varying in population, variants, and potentially all factors above, and therefore may obscure efficacy by including studies where treatment is less effective. Generally, we expect the estimated effect size from meta analysis to be less than that for the optimal case. Looking at all studies is valuable for providing an overview of all research, important to avoid cherry-picking, and informative when a positive result is found despite combining less-optimal situations. However, the resulting estimate does not apply to specific cases such as early treatment in high-risk populations. While we present results for all studies, we also present treatment time and individual outcome analyses, which may be more informative for specific use cases.

Pooled Effects

Pooled effects are no longer required to show harm as of April 2021

This section validates the use of pooled effects for COVID-19, which enables earlier detection of harm, however pooled effects are no longer required for acetaminophen as of April 2021. Harm is now known based on specific outcomes. Harm based on specific outcomes was delayed by 5.4 months compared to using pooled outcomes.

Combining studies is required

For COVID-19, delay in clinical results translates into additional death and morbidity, as well as additional economic and societal damage. Combining the results of studies reporting different outcomes is required. There may be no mortality in a trial with low-risk patients, however a reduction in severity or improved viral clearance may translate into lower mortality in a high-risk population. Different studies may report lower severity, improved recovery, and lower mortality, and the significance may be very high when combining the results. *"The studies reported different outcomes"* is not a good reason for disregarding results. Pooling the results of studies reporting different outcomes allows us to use more of the available information. Logically we should, and do, use additional information when evaluating treatments—for example dose-response and treatment delay-response relationships provide additional evidence of efficacy that is considered when reviewing the evidence for a treatment.

Specific outcome and pooled analyses

We present both specific outcome and pooled analyses. In order to combine the results of studies reporting different outcomes we use the most serious outcome reported in each study, based on the thesis that improvement in the most serious outcome provides comparable measures of efficacy for a treatment. A critical advantage of this

approach is simplicity and transparency. There are many other ways to combine evidence for different outcomes, along with additional evidence such as dose-response relationships, however these increase complexity.

Ethical and practical issues limit high-risk trials

Trials with high-risk patients may be restricted due to ethics for treatments that are known or expected to be effective, and they increase difficulty for recruiting. Using less severe outcomes as a proxy for more serious outcomes allows faster and safer collection of evidence.

Validating pooled outcome analysis for COVID-19

For many COVID-19 treatments, a reduction in mortality logically follows from a reduction in hospitalization, which follows from a reduction in symptomatic cases, which follows from a reduction in PCR positivity. We can directly test this for COVID-19.

Analysis of the the association between different outcomes across studies from all 172 treatments we cover confirms the validity of pooled outcome analysis for COVID-19. Figure 22 shows that lower hospitalization is very strongly associated with lower mortality ($p < 0.000000000001$). Similarly, Figure 23 shows that improved recovery is very strongly associated with lower mortality ($p < 0.000000000001$). Considering the extremes, *Singh et al.* show an association between viral clearance and hospitalization or death, with $p = 0.003$ after excluding one large outlier from a mutagenic treatment, and based on 44 RCTs including 52,384 patients. Figure 24 shows that improved viral clearance is strongly associated with fewer serious outcomes. The association is very similar to *Singh et al.*, with higher confidence due to the larger number of studies. As with *Singh et al.*, the confidence increases when excluding the outlier treatment, from $p = 0.000000082$ to $p = 0.0000000033$.

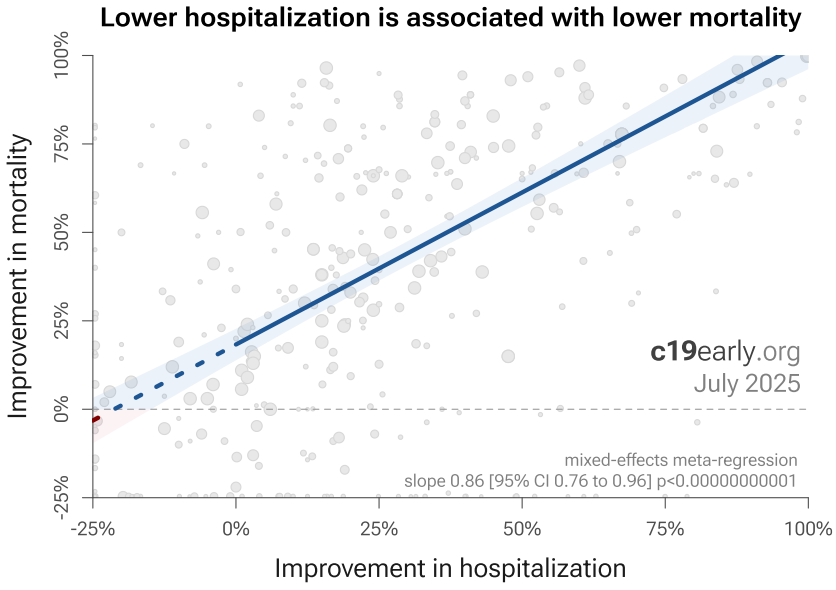


Figure 22. **Lower hospitalization is associated with lower mortality, supporting pooled outcome analysis.**

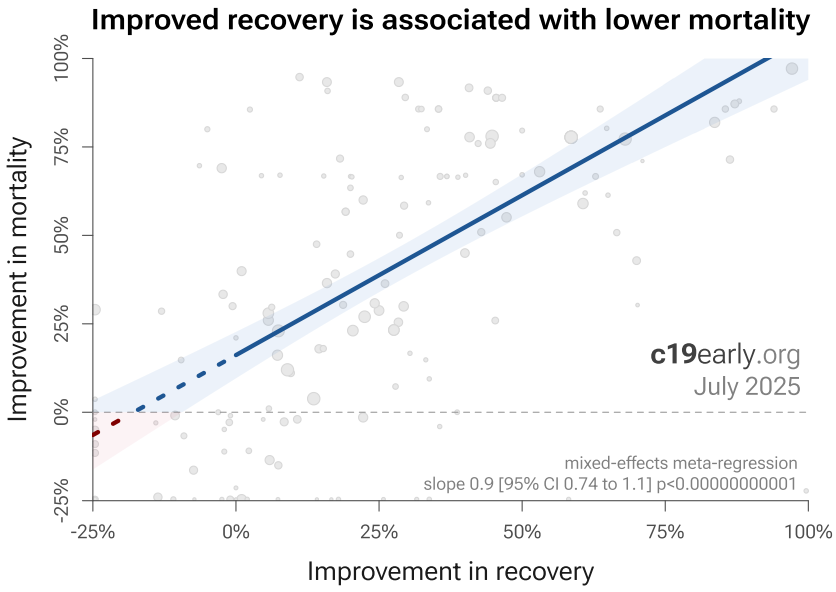


Figure 23. Improved recovery is associated with lower mortality, supporting pooled outcome analysis.

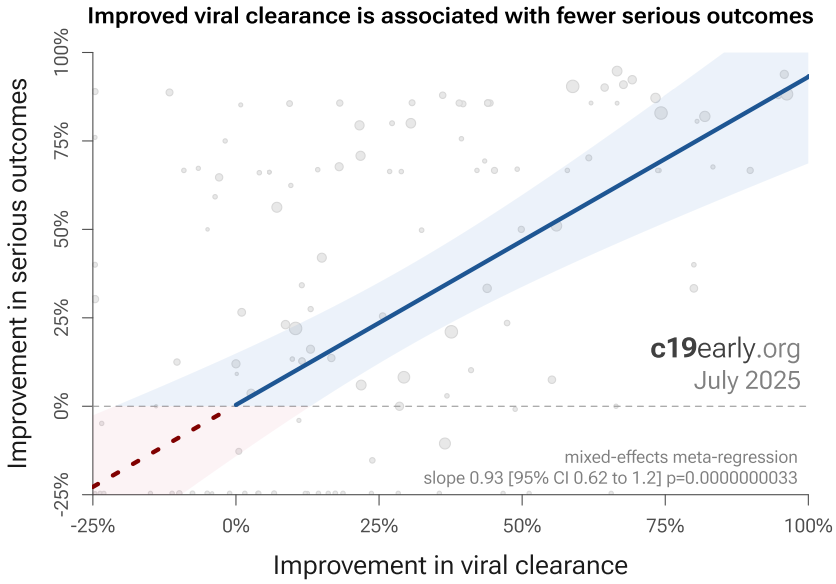


Figure 22. Improved viral clearance is associated with fewer serious outcomes, supporting pooled outcome analysis.

Pooled outcomes identify efficacy 5 months faster (7 months for RCTs)

Currently, 55 of the treatments we analyze show statistically significant efficacy or harm, defined as ≥10% decreased risk or >0% increased risk from ≥3 studies. 88% of these have been confirmed with one or more specific outcomes, with a mean delay of 4.9 months. When restricting to RCTs only, 57% of treatments showing statistically significant efficacy/harm with pooled effects have been confirmed with one or more specific outcomes, with a mean delay of 7.3 months. Figure 25 shows when treatments were found effective during the pandemic. Pooled outcomes often resulted in earlier detection of efficacy.

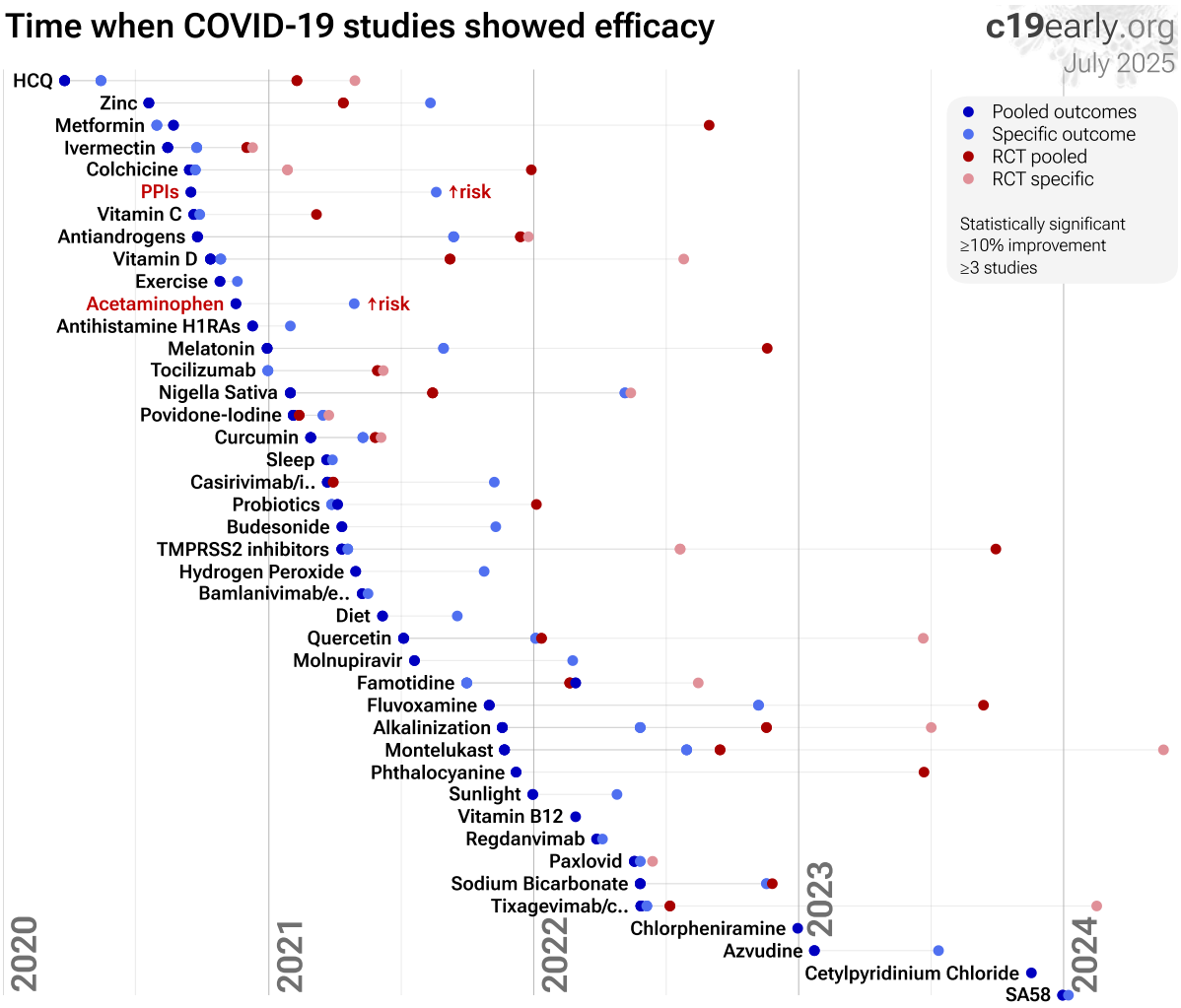


Figure 25. **The time when studies showed that treatments were effective, defined as statistically significant improvement of ≥10% from ≥3 studies.** Pooled results typically show efficacy earlier than specific outcome results. Results from all studies often shows efficacy much earlier than when restricting to RCTs. Results reflect conditions as used in trials to date, these depend on the population treated, treatment delay, and treatment regimen.

Limitations

Pooled analysis could hide efficacy, for example a treatment that is beneficial for late stage patients but has no effect on viral clearance may show no efficacy if most studies only examine viral clearance. In practice, it is rare for a non-antiviral treatment to report viral clearance and to not report clinical outcomes; and in practice other sources of heterogeneity such as difference in treatment delay is more likely to hide efficacy.

Summary

Analysis validates the use of pooled effects and shows significantly faster detection of efficacy on average. However, as with all meta analyses, it is important to review the different studies included. We also present individual outcome analyses, which may be more informative for specific use cases.

Discussion

Results for other infections

Increased risk with acetaminophen has also been shown for rhinovirus[3].

Publication bias

Publishing is often biased towards positive results, however evidence suggests that there may be a negative bias for inexpensive treatments for COVID-19. Both negative and positive results are very important for COVID-19, media in many countries prioritizes negative results for inexpensive treatments (inverting the typical incentive for scientists that value media recognition), and there are many reports of difficulty publishing positive results [57-60]. For acetaminophen, there is currently not enough data to evaluate publication bias with high confidence.

Funnel plot analysis

Funnel plots have traditionally been used for analyzing publication bias. This is invalid for COVID-19 acute treatment trials — the underlying assumptions are invalid, which we can demonstrate with a simple example. Consider a set of hypothetical perfect trials with no bias. Figure 26 plot A shows a funnel plot for a simulation of 80 perfect trials, with random group sizes, and each patient's outcome randomly sampled (10% control event probability, and a 30% effect size for treatment). Analysis shows no asymmetry (p > 0.05). In plot B, we add a single typical variation in COVID-19 treatment trials — treatment delay. Consider that efficacy varies from 90% for treatment within 24 hours, reducing to 10% when treatment is delayed 3 days. In plot B, each trial's treatment delay is randomly selected. Analysis now shows highly significant asymmetry, $p < 0.0001$, with six variants of Egger's test all showing $p < 0.05$ [61-68]. Note that these tests fail even though treatment delay is uniformly distributed. In reality treatment delay is more complex — each trial has a different distribution of delays across patients, and the distribution across trials may be biased (e.g., late treatment trials may be more common). Similarly, many other variations in trials may produce asymmetry, including dose, administration, duration of treatment, differences in SOC, comorbidities, age, variants, and bias in design, implementation, analysis, and reporting.

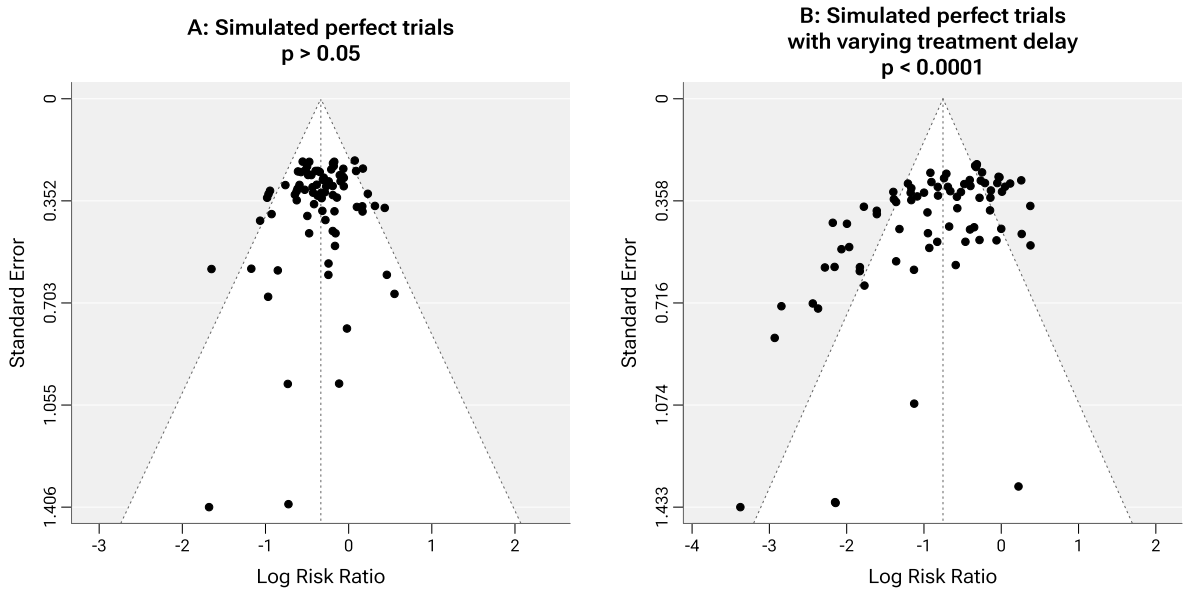


Figure 26. **Example funnel plot analysis for simulated perfect trials.**

Conflicts of interest

Pharmaceutical drug trials often have conflicts of interest whereby sponsors or trial staff have a financial interest in the outcome being positive. Acetaminophen for COVID-19 lacks this because it is off-patent, has multiple manufacturers, and is very low cost.

Limitations

Summary statistics from meta analysis necessarily lose information. As with all meta analyses, studies are heterogeneous, with differences in treatment delay, treatment regimen, patient demographics, variants, conflicts of interest, standard of care, and other factors. We provide analyses for specific outcomes and by treatment delay, and

we aim to identify key characteristics in the forest plots and summaries. Results should be viewed in the context of study characteristics.

Some analyses classify treatment based on early or late administration, as done here, while others distinguish between mild, moderate, and severe cases. Viral load does not indicate degree of symptoms — for example patients may have a high viral load while being asymptomatic. With regard to treatments that have antiviral properties, timing of treatment is critical — late administration may be less helpful regardless of severity.

Details of treatment delay per patient is often not available. For example, a study may treat 90% of patients relatively early, but the events driving the outcome may come from 10% of patients treated very late. Our 5 day cutoff for early treatment may be too conservative, 5 days may be too late in many cases.

Comparison across treatments is confounded by differences in the studies performed, for example dose, variants, and conflicts of interest. Trials with conflicts of interest may use designs better suited to the preferred outcome.

In some cases, the most serious outcome has very few events, resulting in lower confidence results being used in pooled analysis, however the method is simpler and more transparent. This is less critical as the number of studies increases. Restriction to outcomes with sufficient power may be beneficial in pooled analysis and improve accuracy when there are few studies, however we maintain our pre-specified method to avoid any retrospective changes.

Studies show that combinations of treatments can be highly synergistic and may result in many times greater efficacy than individual treatments alone[39-55]. Therefore standard of care may be critical and benefits may diminish or disappear if standard of care does not include certain treatments.

This real-time analysis is constantly updated based on submissions. Accuracy benefits from widespread review and submission of updates and corrections from reviewers. Less popular treatments may receive fewer reviews.

No treatment or intervention is 100% available and effective for all current and future variants. Efficacy may vary significantly with different variants and within different populations. All treatments have potential side effects. Propensity to experience side effects may be predicted in advance by qualified physicians. We do not provide medical advice. Before taking any medication, consult a qualified physician who can compare all options, provide personalized advice, and provide details of risks and benefits based on individual medical history and situations.

Notes

8 of the 27 studies compare against other treatments, which may reduce the effect seen. 1 of 27 studies combine treatments. The results of acetaminophen alone may differ. None of the RCTs use combined treatment.

Reviews

Multiple reviews cover acetaminophen for COVID-19, presenting additional background on mechanisms and related results, including[1,2,69-71].

Perspective

Results compared with other treatments

SARS-CoV-2 infection and replication involves a complex interplay of 100+ host and viral proteins and other factors[72-79], providing many therapeutic targets. Over 9,000 compounds have been predicted to reduce COVID-19 risk[80], either by directly minimizing infection or replication, by supporting immune system function, or by minimizing secondary complications. Figure 27 shows an overview of the results for acetaminophen in the context of multiple COVID-19 treatments, and Figure 28 shows a plot of efficacy vs. cost for COVID-19 treatments.

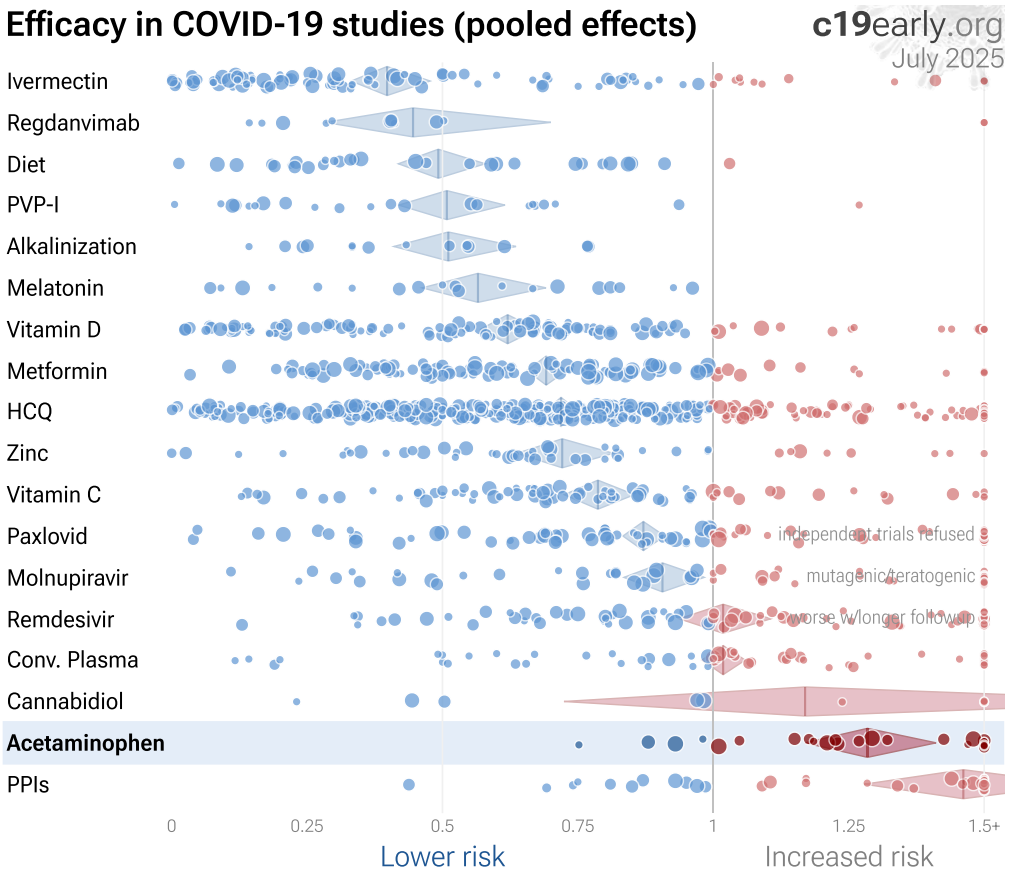


Figure 27. **Scatter plot showing results within the context of multiple COVID-19 treatments.** Diamonds shows the results of random effects meta-analysis. 0.6% of 9,000+ proposed treatments show efficacy[81].

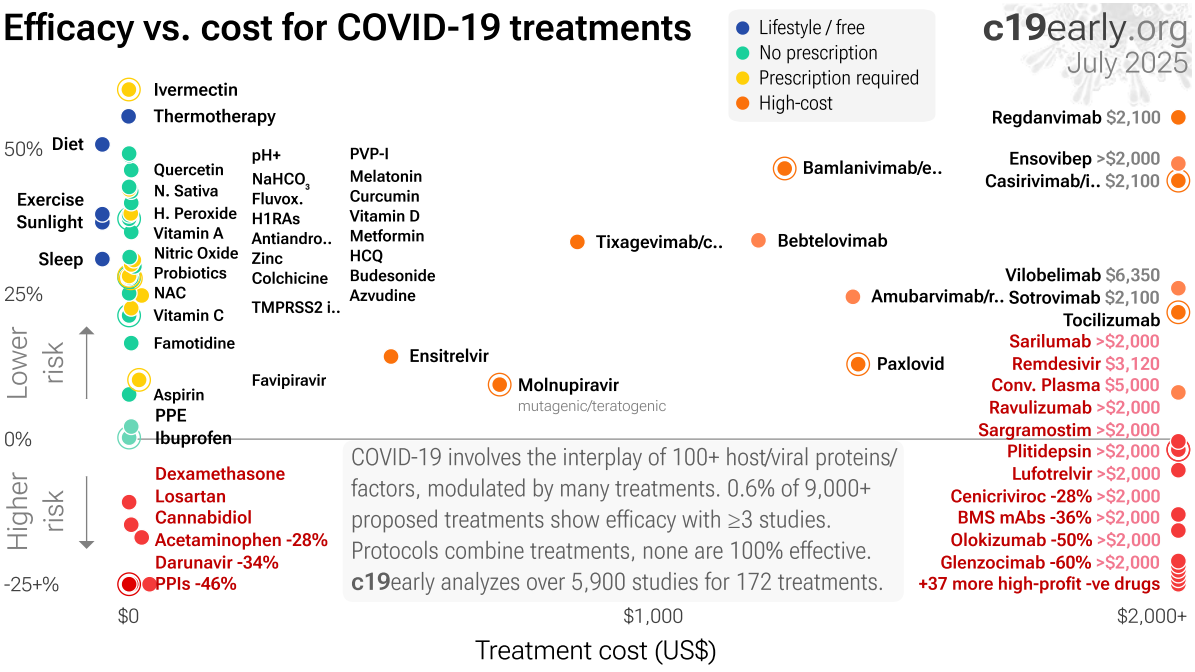


Figure 28. **Efficacy vs. cost for COVID-19 treatments.**

Conclusion

Meta analysis shows 24% [9-40%] higher mortality, and pooled analysis using the most serious outcome reported shows 28% [17-41%] higher risk.

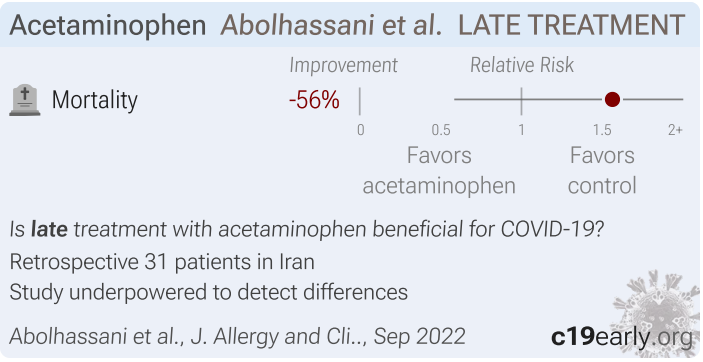
Potential mechanisms of harm include glutathione depletion, fever suppression, liver toxicity, immunosuppression, cytokine disruption, prostaglandin inhibition, COX inhibition, cell/tissue injury, mitochondrial dysfunction, glycine depletion, disruption of redox balance, increased oxidative stress, trace mineral depletion, microbiome alteration, and endocannabinoid system dysfunction.

Concerns have been raised over the use of acetaminophen (paracetamol) for COVID-19[1,2]. Studies show significantly increased risk.

Increased risk with acetaminophen has also been shown for rhinovirus[3].

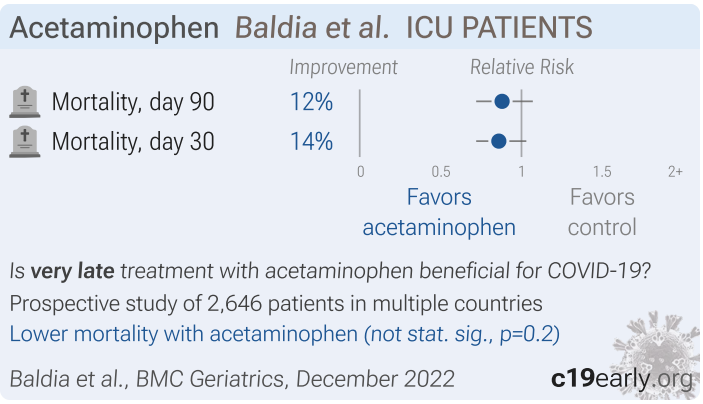
Study Notes

Abolhassani



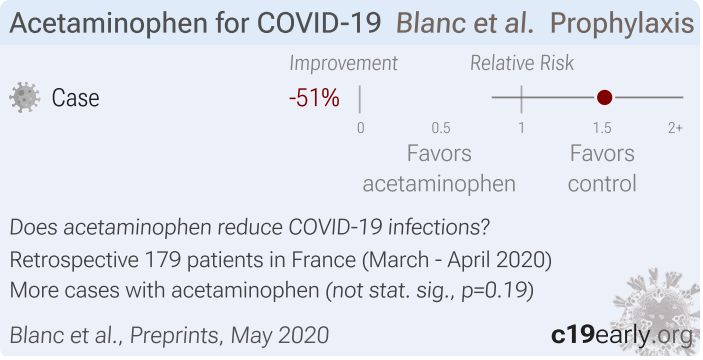
Retrospective 31 hospitalized patients ≤19 with pre-existing inborn errors of immunity, showing no significant difference in mortality with acetaminophen. Only 6 patients were treated with acetaminophen.

Baldia



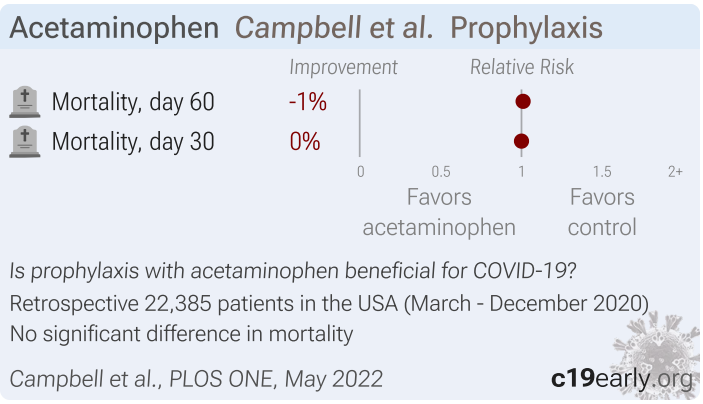
Prospective study of 2,646 ICU patients ≥70 years old, showing no significant difference in mortality with acetaminophen use in the 10 days prior to ICU admission.

Blanc



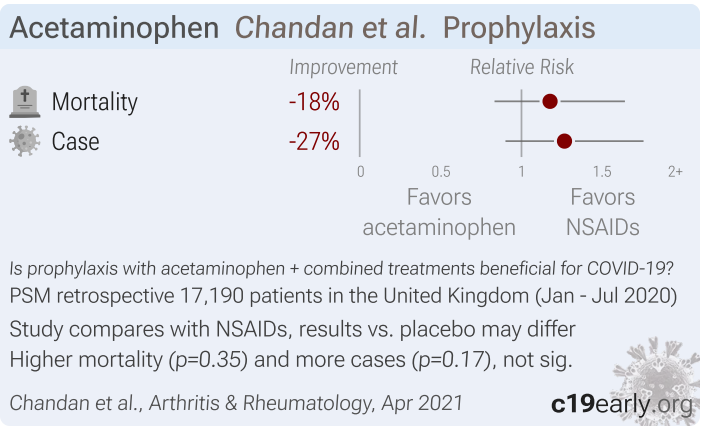
Retrospective 179 elderly patients in France, showing higher risk of COVID-19 cases with acetaminophen use, without statistical significance.

Campbell



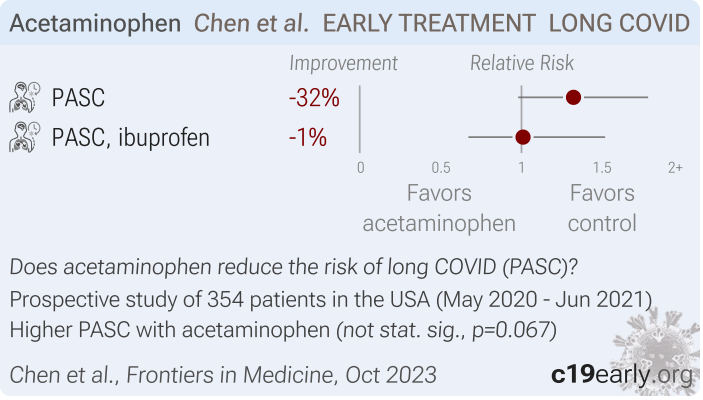
Retrospective 28,856 COVID-19 patients in the USA, showing no significant difference in mortality for chronic acetaminophen use vs. sporadic NSAID use. Since acetaminophen is available OTC and authors only tracked prescriptions, many patients classified as sporadic users may have been chronic users.

Chandan



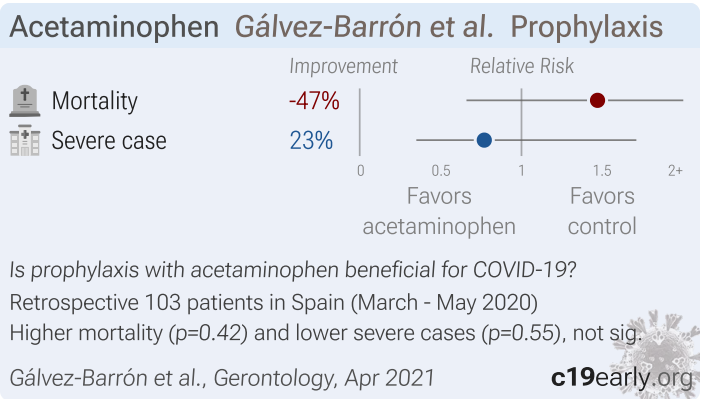
Retrospective 12,457 patients prescribed paracetamol with codeine/dihydrocodeine and 13,202 prescribed NSAIDs, showing no significant differences in cases and mortality. Patients prescribed codeine/dihydrocodeine may have different susceptibility to COVID-19.

Chen



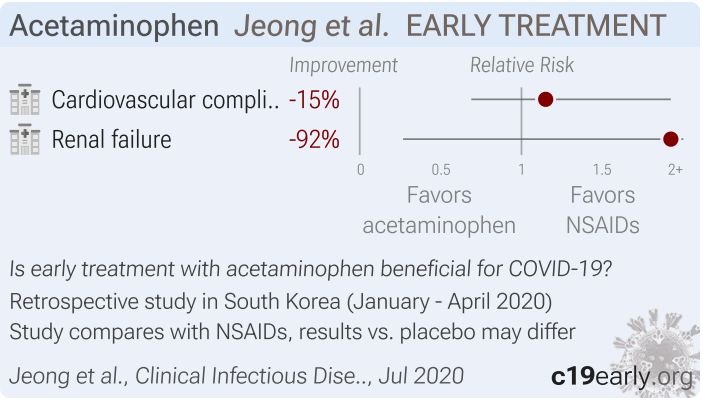
Prospective study of 494 COVID-19 patients showing higher risk of PASC with acetaminophen use in unadjusted results, without reaching statistical significance (p=0.07). Higher risk is also seen for dexamethasone and remdesivir (statistically significant for dexamethasone), however confounding by indication may be significant for these treatments, with increased use for more severe patients. While details of treatment timing and dose are not available, the result for acetaminophen can be compared with ibuprofen, with comparable indication for use. Notably there is no increased risk with ibuprofen, suggesting higher risk with acetaminophen, consistent with the higher risk seen in meta analysis[82].

Gálvez-Barrón



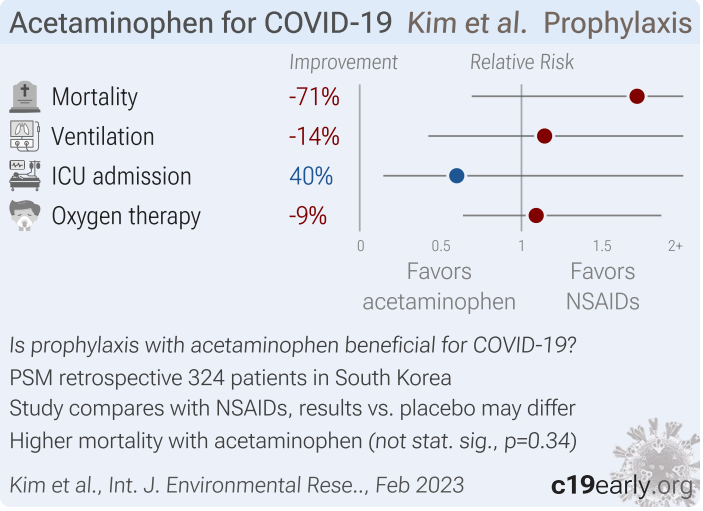
Analysis of 103 elderly hospitalized COVID-19 patients in Spain, showing higher mortality with acetaminophen, without statistical significance.

Jeong



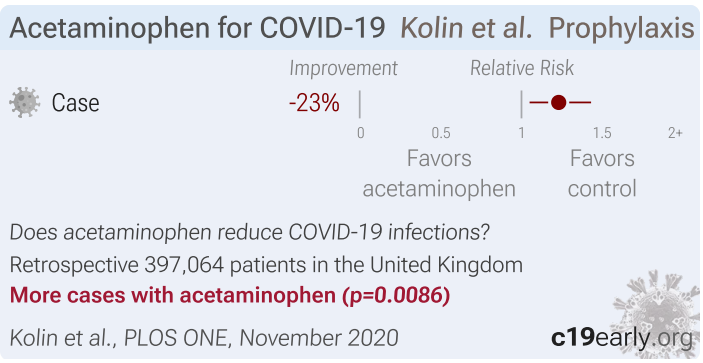
Retrospective 1,824 hospitalized COVID-19 patients in South Korea, showing higher progression to combined death, ICU, ventilation, or sepsis (4% versus 0%, group sizes not provided) with paracetamol vs. NSAIDs. Treatment time may vary - exposure was defined as 7 days before and including cohort entry in hospitalized COVID-19 patients.

Kim



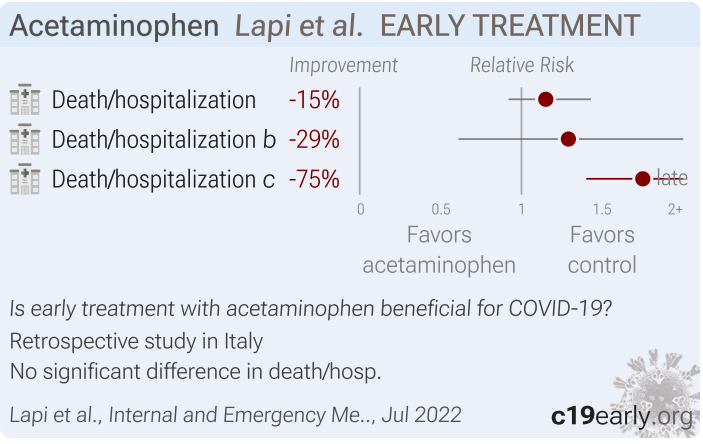
PSM retrospective in South Korea, showing no significant differences in outcomes with acetaminophen use vs. NSAID use. Adherence and dosage are unknown.

Kolin



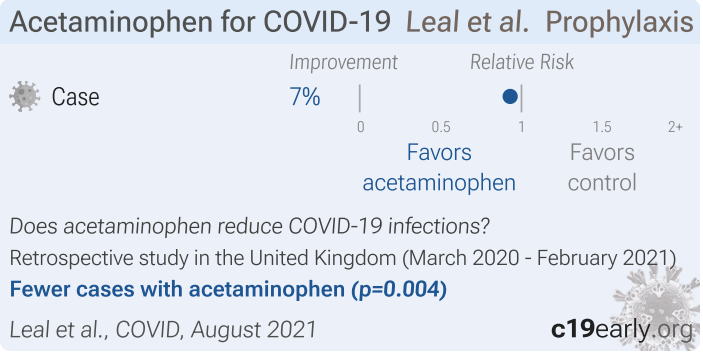
397,064 patient UK Biobank retrospective showing higher risk of COVID-19 with acetaminophen use.

Lapi



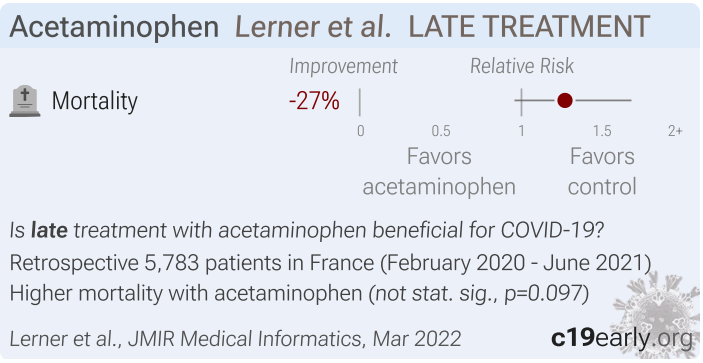
Retrospective paracetamol use with a primary care database in Italy, showing no significant difference in hospitalization/death for use 0-3 and 4-7 days from diagnosis, and significantly higher risk for use >7 days from diagnosis. Confounding by indication may have a greater effect on late usage.

Leal



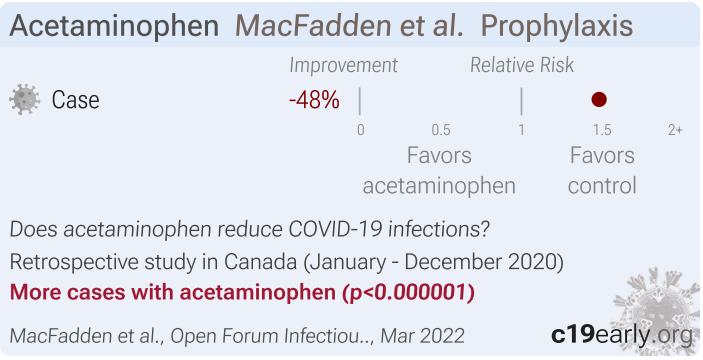
UK Biobank retrospective showing lower cases with acetaminophen use.

Lerner



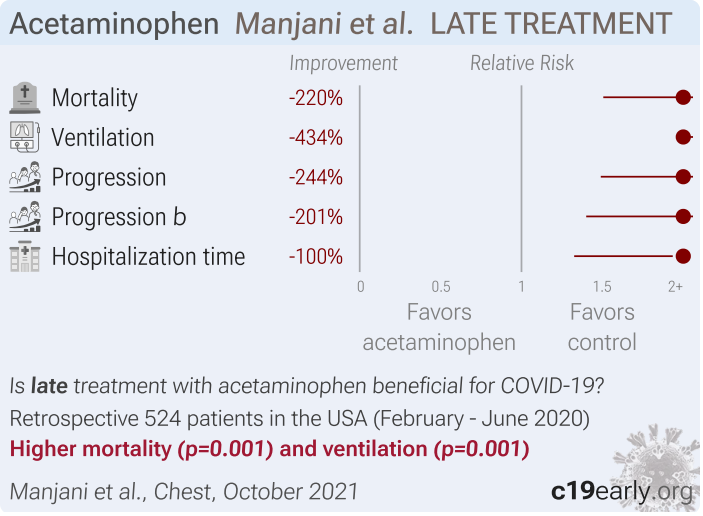
Retrospective 5,783 hospitalized patients in France, showing higher mortality with paracetamol use, without statistical significance.

MacFadden



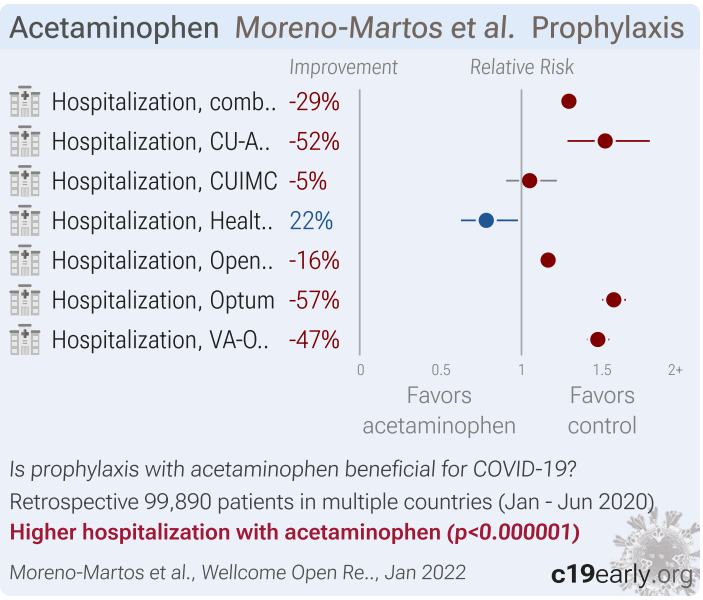
Retrospective 26,121 cases and 2,369,020 controls ≥65yo in Canada, showing higher cases with chronic use of acetaminophen.

Manjani



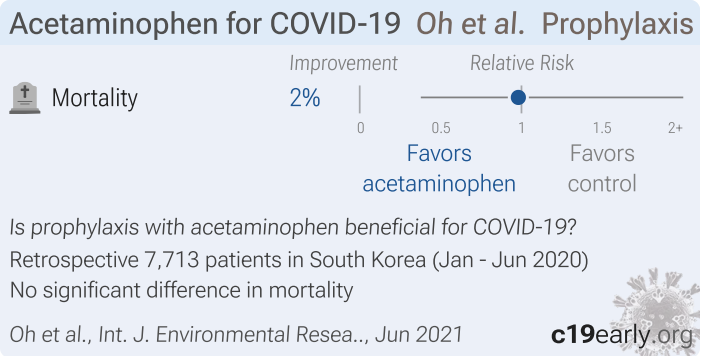
Retrospective 524 hospitalized patients in the USA, showing higher mortality and progression with acetaminophen use.

Moreno-Martos



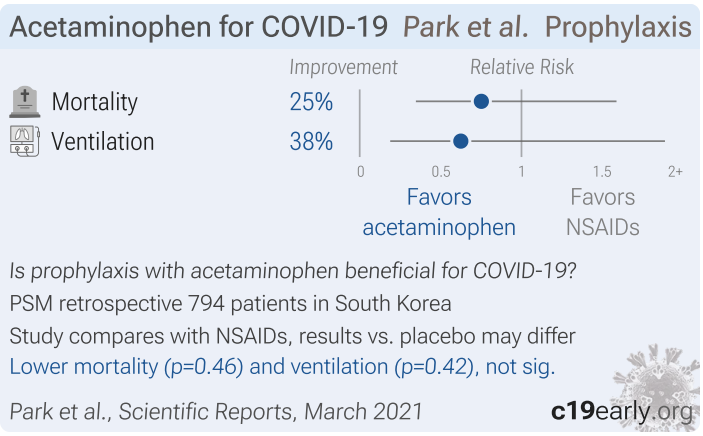
Aanlysis of prescriptions in multiple databases showing higher risk of COVID-19 hospitalization with acetaminophen use for COPD patients. Acetaminophen use was more prevalent in hospitalized patients compared to diagnosed patients (data from tables 1, 5, and S3).

Oh



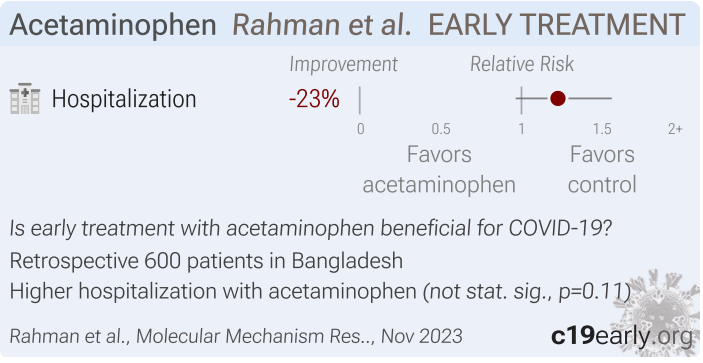
Retrospective 7,713 COVID-19 patients in Korea, showing no significant difference in mortality with paracetamol use.

Park



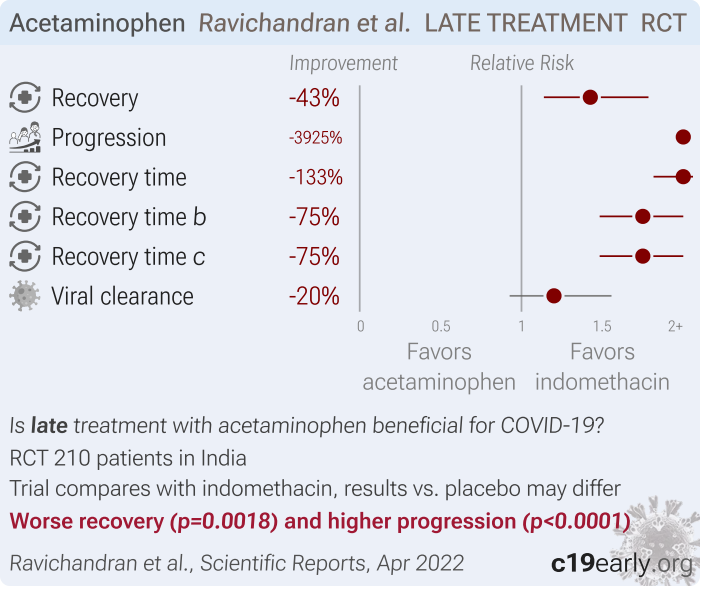
Retrospective 2,365 patients prescribed acetaminophen and 398 prescribed NSAIDs in South Korea, showing no significant differences.

Rahman



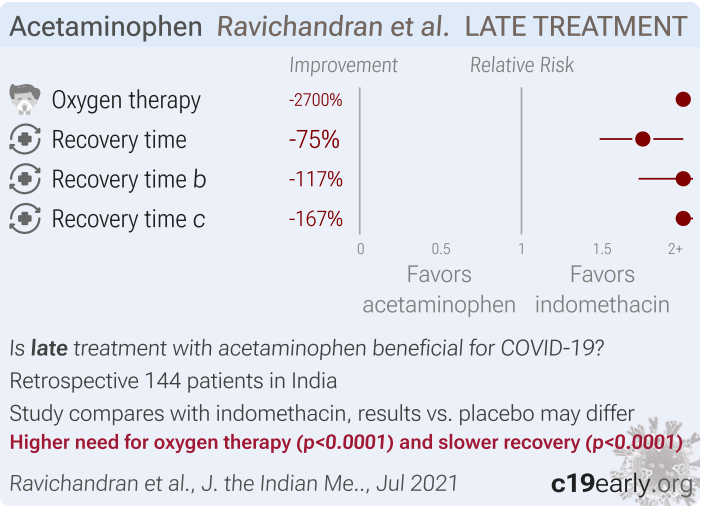
Retrospective 416 non-hospitalized and 184 hospitalized COVID-19 patients in Bangladesh, showing higher acetaminophen and lower vitamin C usage for hospitalized patients. Confounding may be significant and baseline details per treatment group are not provided, however fever and symptomatic patients were more common in the non-hospitalized group. Note there is an alignment mismatch in Table 1.

Ravichandran



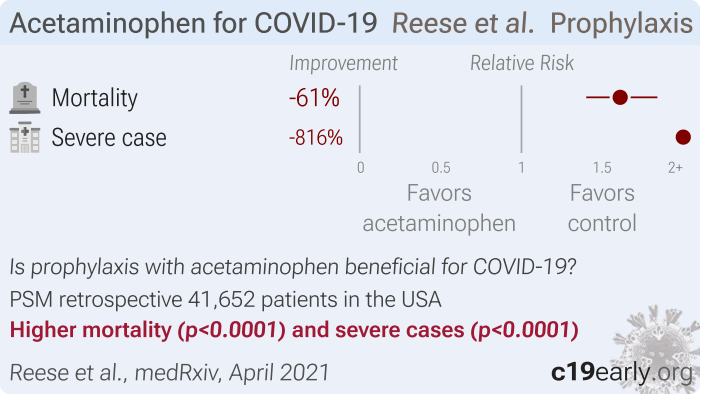
RCT with 107 paracetamol and 103 indomethacin patients, showing higher progression and worse recovery with paracetamol.

Ravichandran



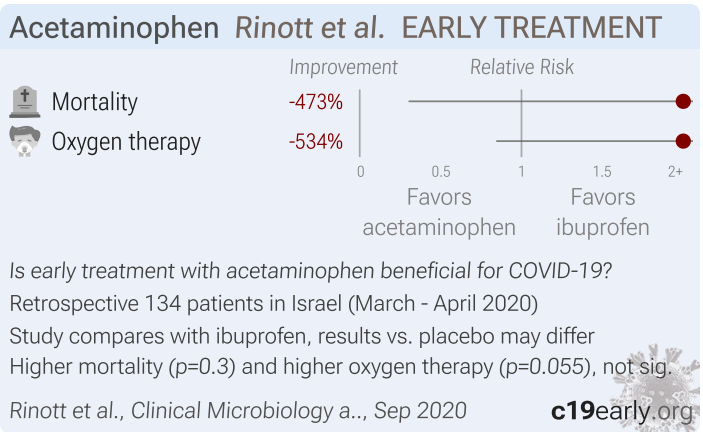
PSM retrospective 72 indomethacin and 72 paracetamol patients in India, showing higher progression and worse recovery with acetaminophen.

Reese



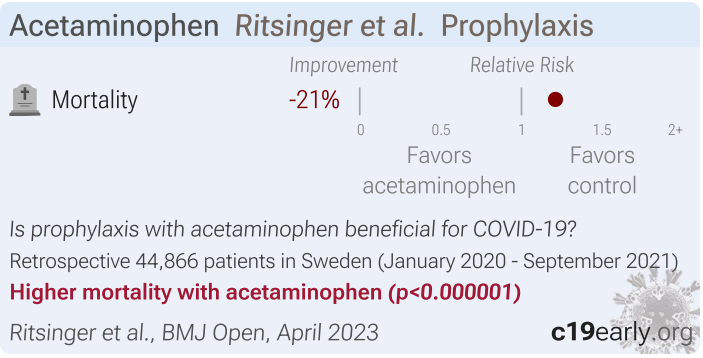
N3C retrospective 250,533 patients showing significantly higher mortality with acetaminophen use. Note that acetaminophen results were not included in the journal version or v2 of this preprint, which focuses on NSAID analysis.

Rinott



Retrospective 89 febrile COVID-19 patients in Israel taking paracetamol and 49 taking ibuprofen, showing higher need for respiratory support with paracetamol. Although not statistically significant, patients in the paracetamol group were older.

Ritsinger

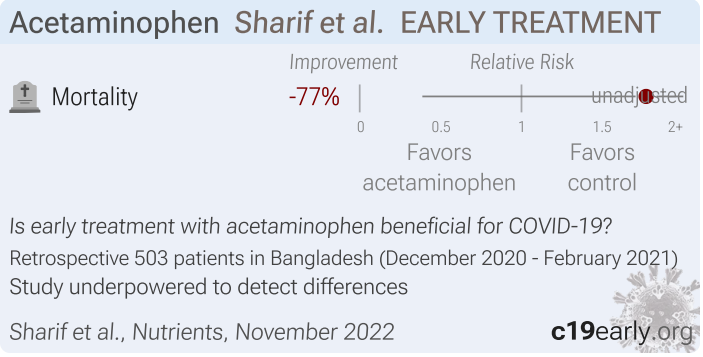


Retrospective 44,866 hospitalized COVID-19 patients in Sweden, showing higher mortality with vitamin D deficiency and with acetaminophen use.

The study focuses on cardiorenal disease, finding higher risk of mortality with CRD. Authors also show that COVID-19

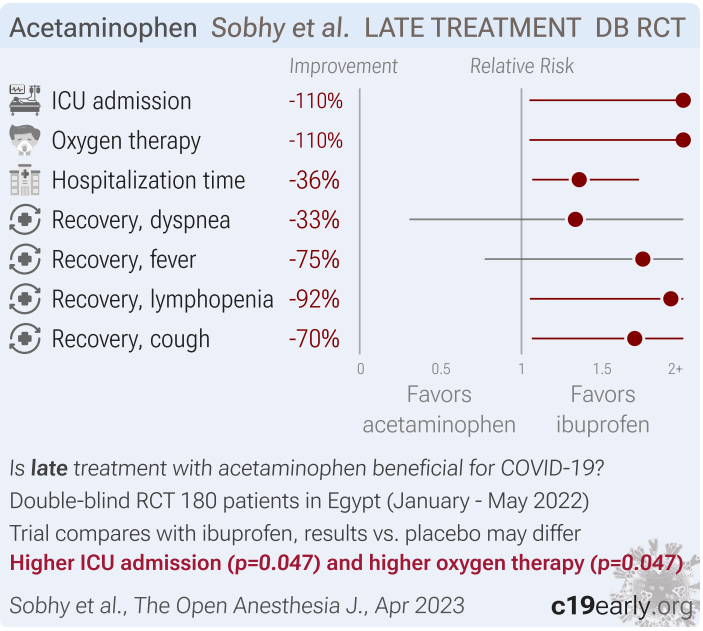
mortality was about 1.5x higher when compared with influenza in the first two pandemic waves, but there was no significant difference in the third wave (HR 1.53 [1.45-1.62] and 1.52 [1.44-1.61] in the first two waves and 1.07 [0.99-1.14] in the third).

Sharif



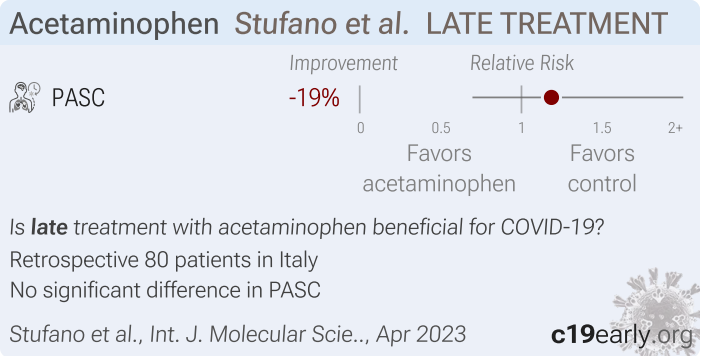
Retrospective COVID-19 patients in Bangladesh, showing higher mortality with acetaminophen use in unadjusted results.

Sobhy



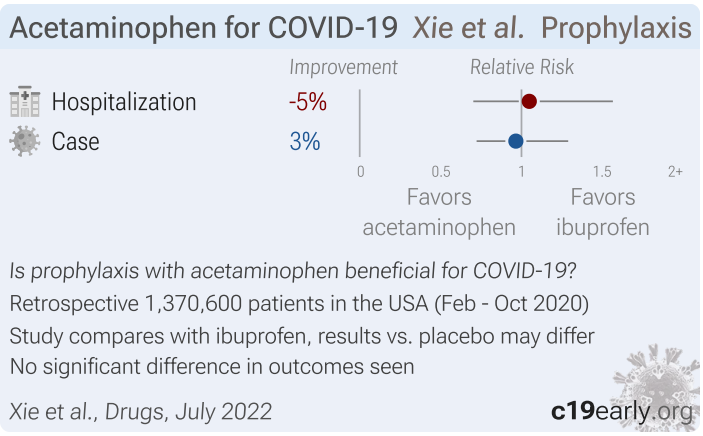
RCT 180 moderate hospitalized COVID-19 patients in Egypt, showing higher ICU admission and longer hospitalization with acetaminophen compared with ibuprofen.

Stufano



Retrospective 80 mild COVID-19 patients in Italy, showing no significant difference in long COVID with acetaminophen use during infection.

Xie



PSM retrospective 1,370,600 osteoarthritis or back pain patients in the US, showing no significant differences in COVID-19 cases and hospitalization for paracetamol vs. ibuprofen.

Appendix 1. Methods and Data

We perform ongoing searches of PubMed, medRxiv, Europe PMC, ClinicalTrials.gov, The Cochrane Library, Google Scholar, Research Square, ScienceDirect, Oxford University Press, the reference lists of other studies and meta-analyses, and submissions to the site c19early.org. Search terms are acetaminophen and COVID-19 or SARS-CoV-2. Automated searches are performed twice daily, with all matches reviewed for inclusion. All studies regarding the use of acetaminophen for COVID-19 that report a comparison with a control group are included in the main analysis. Sensitivity analysis is performed, excluding studies with major issues, epidemiological studies, and studies with minimal available information. Studies with major unexplained data issues, for example major outcome data that is impossible to be correct with no response from the authors, are excluded. This is a living analysis and is updated regularly.

We extracted effect sizes and associated data from all studies. If studies report multiple kinds of effects then the most serious outcome is used in pooled analysis, while other outcomes are included in the outcome specific analyses. For example, if effects for mortality and cases are reported then they are both used in specific outcome analyses, while mortality is used for pooled analysis. If symptomatic results are reported at multiple times, we use the latest time, for example if mortality results are provided at 14 days and 28 days, the results at 28 days have preference. Mortality alone is preferred over combined outcomes. Outcomes with zero events in both arms are not used, the next most serious outcome with one or more events is used. For example, in low-risk populations with no mortality, a reduction in mortality with treatment is not possible, however a reduction in hospitalization, for example, is still valuable.

Clinical outcomes are considered more important than viral outcomes. When basically all patients recover in both treatment and control groups, preference for viral clearance and recovery is given to results mid-recovery where available. After most or all patients have recovered there is little or no room for an effective treatment to do better, however faster recovery is valuable. An IPD meta-analysis confirms that intermediate viral load reduction is more closely associated with hospitalization/death than later viral load reduction [83]. If only individual symptom data is available, the most serious symptom has priority, for example difficulty breathing or low SpO_2 is more important than cough. When results provide an odds ratio, we compute the relative risk when possible, or convert to a relative risk according to *Zhang et al.* Reported confidence intervals and *p*-values are used when available, and adjusted values are used when provided. If multiple types of adjustments are reported propensity score matching and multivariable regression has preference over propensity score matching or weighting, which has preference over multivariable regression. Adjusted results have preference over unadjusted results for a more serious outcome when the adjustments significantly alter results. When needed, conversion between reported *p*-values and confidence intervals followed *Altman, Altman (B)*, and Fisher's exact test was used to calculate *p*-values for event data. If continuity correction for zero values is required, we use the reciprocal of the opposite arm with the sum of the correction factors equal to 1 [87]. Results are expressed with RR < 1.0 favoring treatment, and using the risk of a negative outcome when applicable (for example, the risk of death rather than the risk of survival). If studies only report relative continuous values such as relative times, the ratio of the time for the treatment group versus the time for the control group is used. Calculations are done in Python (3.13.5) with scipy (1.16.0), pythonmeta (1.26), numpy (2.3.1), statsmodels (0.14.4), and plotly (6.2.0).

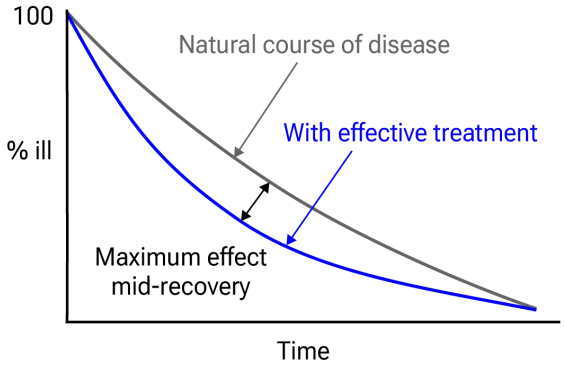


Figure 29. **Mid-recovery results can more accurately reflect efficacy when almost all patients recover.** *Mateja et al.* **confirm that intermediate viral load results more accurately reflect hospitalization/death.**

Forest plots are computed using PythonMeta [88] with the DerSimonian and Laird random effects model (the fixed effect assumption is not plausible in this case) and inverse variance weighting. Results are presented with 95% confidence intervals. Heterogeneity among studies was assessed using the I^2 statistic. Mixed-effects meta-regression results are computed with R (4.4.0) using the metafor (4.6-0) and rms (6.8-0) packages, and using the most serious sufficiently powered outcome. For all statistical tests, a *p*-value less than 0.05 was considered statistically significant. Grobid 0.8.2 is used to parse PDF documents.

We have classified studies as early treatment if most patients are not already at a severe stage at the time of treatment (for example based on oxygen status or lung involvement), and treatment started within 5 days of the onset of symptoms. If studies contain a mix of early treatment and late treatment patients, we consider the treatment time of patients contributing most to the events (for example, consider a study where most patients are treated early but late treatment patients are included, and all mortality events were observed with late treatment patients). We note that a shorter time may be preferable. Antivirals are typically only considered effective when used within a shorter timeframe, for example 0-36 or 0-48 hours for oseltamivir, with longer delays not being effective [24,25].

We received no funding, this research is done in our spare time. We have no affiliations with any pharmaceutical companies or political parties.

A summary of study results is below. Please submit updates and corrections at https://c19early.org/acemeta.html.

Early treatment

Effect extraction follows pre-specified rules as detailed above and gives priority to more serious outcomes. For pooled analyses, the first (most serious) outcome is used, which may differ from the effect a paper focuses on. Other outcomes are used in outcome specific analyses.

Chen (B), 10/16/2023, prospective, USA, peer-reviewed, 17 authors, study period May 2020 - June 2021.	risk of PASC, 32.1% higher, RR 1.32, $p = 0.07$, treatment 98 of 232 (42.2%), control 39 of 122 (32.0%).

	risk of PASC, 0.9% higher, RR 1.01, p = 1.00, treatment 16 of 41 (39.0%), control 121 of 313 (38.7%), ibuprofen.
Lapi, 7/30/2022, retrospective, Italy, peer-reviewed, 8 authors, early treatment subset.	risk of death/hospitalization, 15.0% higher, OR 1.15, p = 0.22, adjusted per study, early use, RR approximated with OR.
	risk of death/hospitalization, 29.0% higher, OR 1.29, p = 0.52, adjusted per study, mid-term use, RR approximated with OR.
Rahman, 11/8/2023, retrospective, Bangladesh, peer-reviewed, 5 authors, excluded in exclusion analyses: unadjusted results with no group details; significant unadjusted confounding possible.	risk of hospitalization, 22.6% higher, RR 1.23, p = 0.11, treatment 84 of 244 (34.4%), control 100 of 356 (28.1%).
Rinott, 9/30/2020, retrospective, Israel, peer-reviewed, median age 45.0, 5 authors, study period 15 March, 2020 - 15 April, 2020, this trial compares with another treatment - results may be better when compared to placebo, excluded in exclusion analyses: unadjusted differences between groups.	risk of death, 472.9% higher, RR 5.73, p = 0.30, treatment 3 of 85 (3.5%), control 0 of 49 (0.0%), continuity correction due to zero event (with reciprocal of the contrasting arm).
	risk of oxygen therapy, 534.1% higher, RR 6.34, p = 0.06, treatment 11 of 85 (12.9%), control 1 of 49 (2.0%).
Sharif, 11/26/2022, retrospective, Bangladesh, peer-reviewed, 14 authors, study period 13 December, 2020 - 4 February, 2021, excluded in exclusion analyses: unadjusted results with no group details.	risk of death, 77.0% higher, RR 1.77, p = 0.74, treatment 9 of 361 (2.5%), control 2 of 142 (1.4%), unadjusted, ACE.

Late treatment

Effect extraction follows pre-specified rules as detailed above and gives priority to more serious outcomes. For pooled analyses, the first (most serious) outcome is used, which may differ from the effect a paper focuses on. Other outcomes are used in outcome specific analyses.

Abolhassani, 9/13/2022, retrospective, Iran, peer-reviewed, 23 authors.	risk of death, 56.2% higher, RR 1.56, p = 0.64, treatment 3 of 6 (50.0%), control 8 of 25 (32.0%).
Baldia, 12/27/2022, prospective, multiple countries, peer-reviewed, median age 75.0, 26 authors, trial NCT04321265 (history).	risk of death, 12.0% lower, OR 0.88, p = 0.20, treatment 1,166, control 1,480, adjusted per study, multivariable, day 90, RR approximated with OR.
	risk of death, 14.0% lower, OR 0.86, p = 0.20, treatment 1,166, control 1,480, adjusted per study, multivariable, day 30, RR approximated with OR.
Lapi, 7/30/2022, retrospective, Italy, peer-reviewed, 8 authors, excluded in exclusion analyses: substantial unadjusted confounding by indication likely.	risk of death/hospitalization, 75.0% higher, OR 1.75, p < 0.001, adjusted per study, late use, RR approximated with OR, late treatment result.
Lerner, 3/30/2022, retrospective, France, peer-reviewed, median age 69.2, 7 authors, study period 1 February, 2020 - 15 June, 2021.	risk of death, 26.9% higher, RR 1.27, p = 0.10, odds ratio converted to relative risk, weighted and trimmed, day 28, control prevalance approximated with overall prevalence.
Manjani, 10/31/2021, retrospective, USA, peer-reviewed, 6 authors, study period February 2020 - June 2020.	risk of death, 220.5% higher, RR 3.20, p = 0.001, treatment 64 of 388 (16.5%), control 7 of 136 (5.1%).
	risk of mechanical ventilation, 434.5% higher, RR 5.34, p < 0.001, treatment 388, control 136.

	risk of progression, 244.0% higher, OR 3.44, $p < 0.005$, treatment 132, control 136, triaged to higher level of care, high exposure, RR approximated with OR.
	risk of progression, 201.0% higher, OR 3.01, $p < 0.007$, treatment 256, control 136, triaged to higher level of care, moderate exposure, RR approximated with OR.
	hospitalization time, 100% higher, relative time 2.00, $p < 0.001$, treatment 388, control 136.
Ravichandran, 4/19/2022, Randomized Controlled Trial, India, peer-reviewed, 8 authors, this trial compares with another treatment - results may be better when compared to placebo, trial CTRI/2021/05/033544.	**risk of no recovery, 42.5% higher, RR 1.43, $p = 0.002$**, treatment 77 of 107 (72.0%), control 52 of 103 (50.5%), day 14.
	risk of progression, 3925.2% higher, RR 40.25, $p < 0.001$, treatment 20 of 107 (18.7%), control 0 of 103 (0.0%), continuity correction due to zero event (with reciprocal of the contrasting arm), SpO2 ≤93.
	recovery time, 133.3% higher, relative time 2.33, $p < 0.001$, treatment median 7.0 IQR 2.75 n=107, control median 3.0 IQR 1.0 n=103, fever.
	recovery time, 75.0% higher, relative time 1.75, $p < 0.001$, treatment median 7.0 IQR 2.0 n=107, control median 4.0 IQR 2.0 n=103, myalgia.
	recovery time, 75.0% higher, relative time 1.75, $p < 0.001$, treatment median 7.0 IQR 3.0 n=107, control median 4.0 IQR 1.0 n=103, cough.
	risk of no viral clearance, 20.1% higher, RR 1.20, $p = 0.19$, treatment 43 of 60 (71.7%), control 37 of 62 (59.7%), day 7.
Ravichandran (B), 7/31/2021, retrospective, India, peer-reviewed, 6 authors, this trial compares with another treatment - results may be better when compared to placebo, trial ISRCTN11970082.	**risk of oxygen therapy, 2700.0% higher, RR 28.00, $p < 0.001$**, treatment 28 of 72 (38.9%), control 1 of 72 (1.4%), propensity score matching.
	recovery time, 75.0% higher, relative time 1.75, $p < 0.001$, treatment median 7.0 IQR 1.0 n=72, control median 4.0 IQR 1.0 n=72, fever.
	recovery time, 116.7% higher, relative time 2.17, $p < 0.001$, treatment median 6.5 IQR 3.25 n=72, control median 3.0 IQR 2.0 n=72, myalgia.
	recovery time, 166.7% higher, relative time 2.67, $p < 0.001$, treatment median 8.0 IQR 2.0 n=72, control median 3.0 IQR 2.0 n=72, cough.
Sobhy, 4/19/2023, Double Blind Randomized Controlled Trial, Egypt, peer-reviewed, 6 authors, study period January 2022 - May 2022, this trial compares with another treatment - results may be better when compared to placebo, trial PACTR202202880140319.	**risk of ICU admission, 110.0% higher, RR 2.10, $p = 0.047$**, treatment 21 of 90 (23.3%), control 10 of 90 (11.1%).
	risk of oxygen therapy, 110.0% higher, RR 2.10, $p = 0.047$, treatment 21 of 90 (23.3%), control 10 of 90 (11.1%).
	hospitalization time, 35.7% higher, relative time 1.36, $p = 0.01$, treatment 90, control 90.
	risk of no recovery, 33.3% higher, RR 1.33, $p = 1.00$, treatment 4 of 90 (4.4%), control 3 of 90 (3.3%), day 4, dyspnea.

	risk of no recovery, 75.0% higher, RR 1.75, p = 0.25, treatment 14 of 90 (15.6%), control 8 of 90 (8.9%), day 4, fever.
	risk of no recovery, 92.3% higher, RR 1.92, p = 0.04, treatment 25 of 90 (27.8%), control 13 of 90 (14.4%), day 4, lymphopenia.
	risk of no recovery, 70.0% higher, RR 1.70, p = 0.03, treatment 34 of 90 (37.8%), control 20 of 90 (22.2%), day 4, cough.
Stufano, 4/18/2023, retrospective, Italy, peer-reviewed, 7 authors.	**risk of PASC, 18.5% higher, RR 1.19, p = 0.62**, treatment 11 of 23 (47.8%), control 23 of 57 (40.4%).

Prophylaxis

Effect extraction follows pre-specified rules as detailed above and gives priority to more serious outcomes. For pooled analyses, the first (most serious) outcome is used, which may differ from the effect a paper focuses on. Other outcomes are used in outcome specific analyses.

Blanc, 5/2/2020, retrospective, France, preprint, mean age 84.1, 22 authors, study period 2 March, 2020 - 8 April, 2020.	**risk of case, 51.4% higher, OR 1.51, p = 0.19**, treatment 60, control 119, RR approximated with OR.
Campbell, 5/5/2022, retrospective, USA, peer-reviewed, 4 authors, study period 2 March, 2020 - 14 December, 2020.	**risk of death, 1.0% higher, OR 1.01, p = 0.43**, treatment 2,074, control 20,311, adjusted per study, propensity score weighting, multivariable, day 60, RR approximated with OR.
	risk of death, no change, OR 1.00, p = 0.86, treatment 2,074, control 20,311, adjusted per study, propensity score weighting, multivariable, day 30, RR approximated with OR.
Chandan, 4/29/2021, retrospective, United Kingdom, peer-reviewed, mean age 65.4, 24 authors, study period 30 January, 2020 - 31 July, 2020, this trial compares with another treatment - results may be better when compared to placebo, this trial uses multiple treatments in the treatment arm (combined with codeine or dihydrocodeine) - results of individual treatments may vary.	**risk of death, 17.6% higher, HR 1.18, p = 0.35**, treatment 71 of 8,595 (0.8%), control 79 of 8,595 (0.9%), adjusted per study, inverted to make HR<1 favor treatment, propensity score matching, multivariable.
	risk of case, 26.6% higher, HR 1.27, p = 0.17, treatment 8,595, control 8,595, adjusted per study, inverted to make HR<1 favor treatment, propensity score matching, multivariable.
Gálvez-Barrón, 4/14/2021, retrospective, Spain, peer-reviewed, mean age 86.8, 13 authors, study period 12 March, 2020 - 2 May, 2020.	**risk of death, 47.0% higher, OR 1.47, p = 0.42**, treatment 43, control 60, RR approximated with OR.
	risk of severe case, 23.0% lower, OR 0.77, p = 0.55, treatment 43, control 60, RR approximated with OR.
Kim, 2/21/2023, retrospective, South Korea, peer-reviewed, mean age 55.8, 4 authors, this trial compares with another treatment - results may be better when compared to placebo.	**risk of death, 71.4% higher, RR 1.71, p = 0.34**, treatment 12 of 162 (7.4%), control 7 of 162 (4.3%), propensity score matching.
	risk of mechanical ventilation, 14.3% higher, RR 1.14, p = 1.00, treatment 8 of 162 (4.9%), control 7 of 162 (4.3%), propensity score matching.
	risk of ICU admission, 40.0% lower, RR 0.60, p = 0.72, treatment 3 of 162 (1.9%), control 5 of 162 (3.1%), NNT 81, propensity score matching.
	risk of oxygen therapy, 9.1% higher, RR 1.09, p = 0.87, treatment 24 of 162 (14.8%), control 22 of 162 (13.6%), propensity score matching.

Kolin, 11/17/2020, retrospective, United Kingdom, peer-reviewed, 4 authors.	risk of case, 23.0% higher, RR 1.23, $p = 0.009$.
Leal, 8/16/2021, retrospective, United Kingdom, peer-reviewed, 5 authors, study period 16 March, 2020 - 1 February, 2021.	risk of case, 7.0% lower, OR 0.93, $p = 0.004$, RR approximated with OR.
MacFadden, 3/29/2022, retrospective, Canada, peer-reviewed, 9 authors, study period 15 January, 2020 - 31 December, 2020.	risk of case, 48.0% higher, OR 1.48, $p < 0.001$, RR approximated with OR.
Moreno-Martos, 1/24/2022, retrospective, multiple countries, peer-reviewed, 24 authors, study period January 2020 - June 2020.	risk of hospitalization, 29.3% higher, RR 1.29, $p < 0.001$, treatment 10,367, control 89,523, meta analysis of all databases combined.
	risk of hospitalization, 51.7% higher, RR 1.52, $p < 0.001$, treatment 103 of 178 (57.9%), control 196 of 514 (38.1%), US CU-AMC.
	risk of hospitalization, 5.1% higher, RR 1.05, $p = 0.57$, treatment 87 of 144 (60.4%), control 360 of 626 (57.5%), US CUIMC.
	risk of hospitalization, 21.8% lower, RR 0.78, $p = 0.02$, treatment 64 of 319 (20.1%), control 1,585 of 6,181 (25.6%), NNT 18, US HealthVerity.
	risk of hospitalization, 16.5% higher, RR 1.16, $p < 0.001$, treatment 2,597 of 4,983 (52.1%), control 28,320 of 63,279 (44.8%), US IQVIA OpenClaims.
	risk of hospitalization, 57.0% higher, RR 1.57, $p < 0.001$, treatment 1,090 of 1,868 (58.4%), control 3,414 of 9,188 (37.2%), US Optum EHR.
	risk of hospitalization, 47.2% higher, RR 1.47, $p < 0.001$, treatment 1,397 of 2,875 (48.6%), control 3,214 of 9,735 (33.0%), US VA-OMOP.
Oh, 6/24/2021, retrospective, South Korea, peer-reviewed, 5 authors, study period 1 January, 2020 - 4 June, 2020.	risk of death, 1.9% lower, RR 0.98, $p = 0.97$, treatment 58, control 7,655, adjusted per study, odds ratio converted to relative risk, multivariable, control prevalance approximated with overall prevalence.
Park, 3/3/2021, retrospective, South Korea, peer-reviewed, 5 authors, this trial compares with another treatment - results may be better when compared to placebo.	risk of death, 24.8% lower, HR 0.75, $p = 0.46$, treatment 12 of 397 (3.0%), control 16 of 397 (4.0%), NNT 99, inverted to make HR<1 favor treatment, propensity score matching.
	risk of mechanical ventilation, 37.5% lower, HR 0.62, $p = 0.42$, treatment 5 of 397 (1.3%), control 8 of 397 (2.0%), NNT 132, inverted to make HR<1 favor treatment, propensity score matching.
Reese, 4/20/2021, retrospective, USA, preprint, 23 authors.	risk of death, 61.0% higher, HR 1.61, $p < 0.001$, treatment 20,826, control 20,826, propensity score matching, Cox proportional hazards, Table S58.
	risk of severe case, 816.0% higher, OR 9.16, $p < 0.001$, treatment 20,826, control 20,826, propensity score matching, Table S50, RR approximated with OR.
Ritsinger, 4/28/2023, retrospective, Sweden, peer-reviewed, mean age 79.8, 8 authors, study period 1 January, 2020 - 9 September, 2021.	risk of death, 21.0% higher, HR 1.21, $p < 0.001$, treatment 24,641, control 20,225.

Xie (B), 7/13/2022, retrospective, USA, peer-reviewed, 9 authors, study period 1 February, 2020 - 31 October, 2020, this trial compares with another treatment - results may be better when compared to placebo.	risk of hospitalization, 4.8% higher, HR 1.05, $p = 0.83$, inverted to make HR<1 favor treatment, Open Claims, PharMetrics Plus, both periods combined.
	risk of case, 3.5% lower, HR 0.97, $p = 0.82$, inverted to make HR<1 favor treatment, Open Claims, PharMetrics Plus, both periods combined.

Supplementary Data

Supplementary Data

References

1. **Pandolfi** et al., *Paracetamol in the home treatment of early COVID-19 symptoms: A possible foe rather than a friend for elderly patients?*, Journal of Medical Virology, doi:10.1002/jmv.27158.
2. **Sestili** et al., *Paracetamol-Induced Glutathione Consumption: Is There a Link With Severe COVID-19 Illness?*, Frontiers in Pharmacology, doi:10.3389/fphar.2020.579944.
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