Effects of public health interventions against COVID-19 in France

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METHODS

- Geographic scope: 94 non-insular departments in France
- Study period: March 2020 - October 2021, spanning three waves
- Modeling approach: **Mechanistic model**, consisting of:

1. A **mathematical model** based on ordinary differential equations to describe the dynamics of SARS-CoV-2 transmission

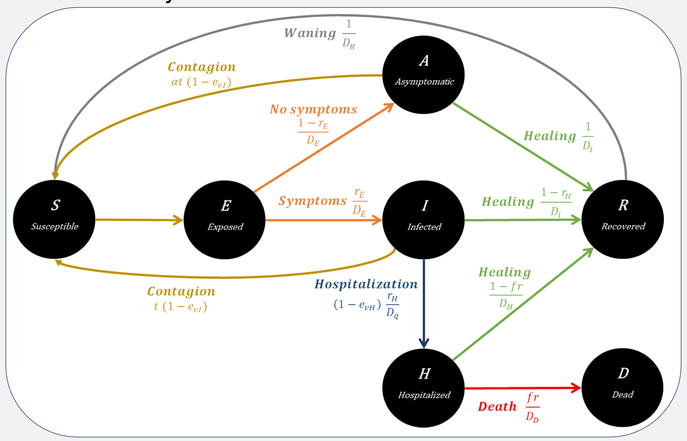

Fig 1: Schematic of the transmission model

2. A **statistical mixed effects model** to describe how the transmission rate varies over time as a function of NPIs, vaccinations, seasonality, and variants of concern (VoCs)

$$\log(t_{i,t}) = b_{0i} * \exp(\sum_j \beta^j NPI^j_{i,t} + \sum_k \beta^k_V VoC^k_{i,t} + \beta_w weather_{i,t})$$

$b_{0i} \sim \mathcal{N}\left(b_{0_{pop}}, \omega\right)$ for department *i* at time *t*, NPI *j* and VoC *k*.

3. An **observation model:** Observations of hospital admissions and occupancy, cases, and deaths with noise

- Parameter estimations were performed with Monolix™ software

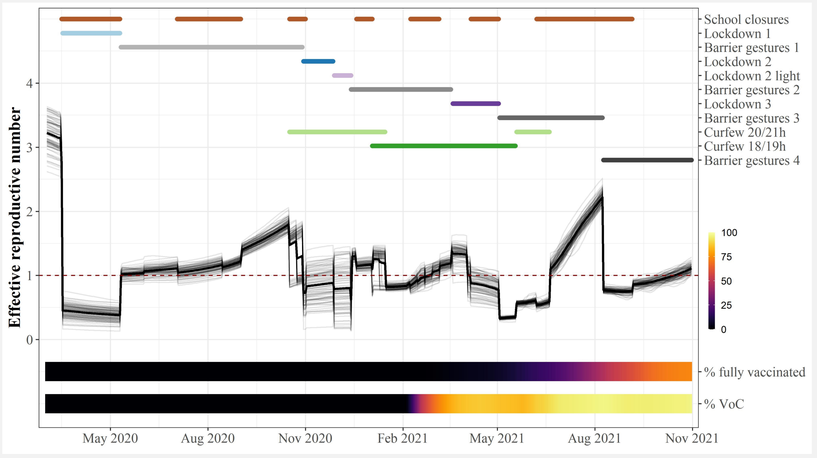

Fig 2: Effective reproductive number (R_t) as estimated by the model in relation to implemented NPIs, variants of concern (VoC) and vaccinations.

RESULTS

Vaccines and governmental non-pharmaceutical interventions against COVID-19 effectively reduced COVID-19 infections, hospitalizations, and deaths.

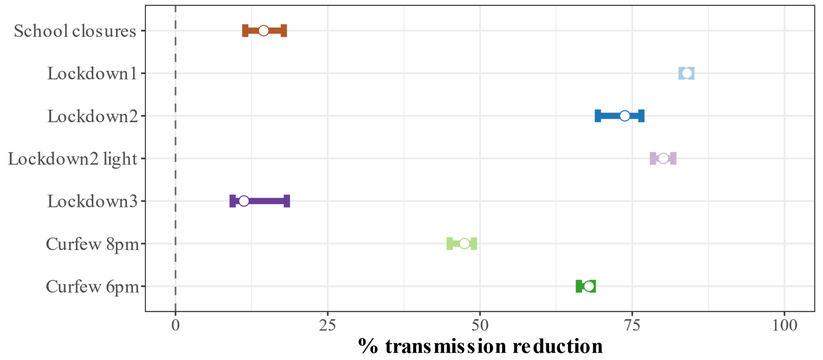

Fig 3: Effect of NPIs. Markers represent median percentage reduction in transmission along with 95% confidence intervals. The effectiveness estimates were calculated as $100\left[1-\exp\left(\beta^j\right)\right]$. All NPIs implemented in France effectively reduced viral transmission, but the effectiveness of lockdown interventions decreased over time.

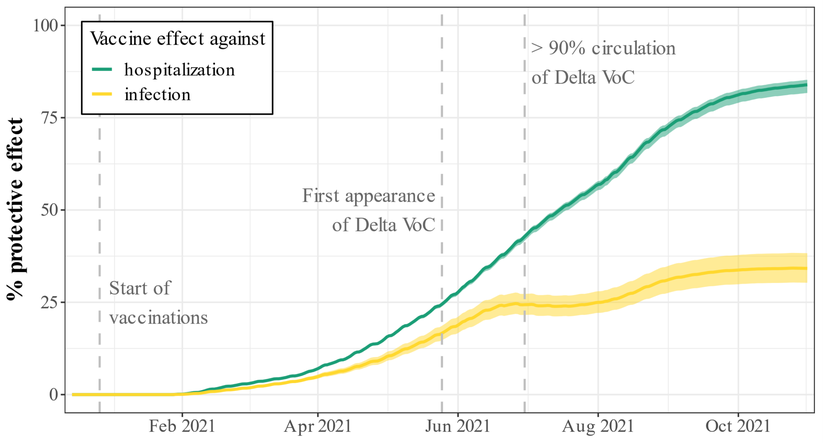

Fig 4: Estimated protective effect conferred by vaccination. We separately evaluated the vaccines' impact as the population vaccine effect against infection (e_{vI}) and against hospitalization (e_{vH}). The vaccine effects take into account not only the vaccine effectiveness, but also the population vaccine coverage, and were calculated as $e_{vI} = VE_{I1}cov_{dose1}(1-cov_\delta) + VE_{I2}cov_{dose2}(1-cov_\delta) + VE_{I2\delta}cov_{dose2}cov_\delta$ and $e_{vH} = VE_{H1}cov_{dose1} + VE_{H2}cov_{dose2}$ where e_v is overall vaccine effect, VE_1 and VE_2 are vaccine effectiveness with 1 or 2 doses, respectively, and cov is the population vaccine coverage. As the Delta VoC considerably decreased VE_I, we included a discounting factor that depends on the percent of circulating Delta VoC. With increasing population vaccine coverage e_{vH} and e_{vI} increased as well. However, with the emergence of the Delta VoC in France, e_{vI} plateaus around 35%, while e_{vH} plateaus around 80%.

PREDICTIONS

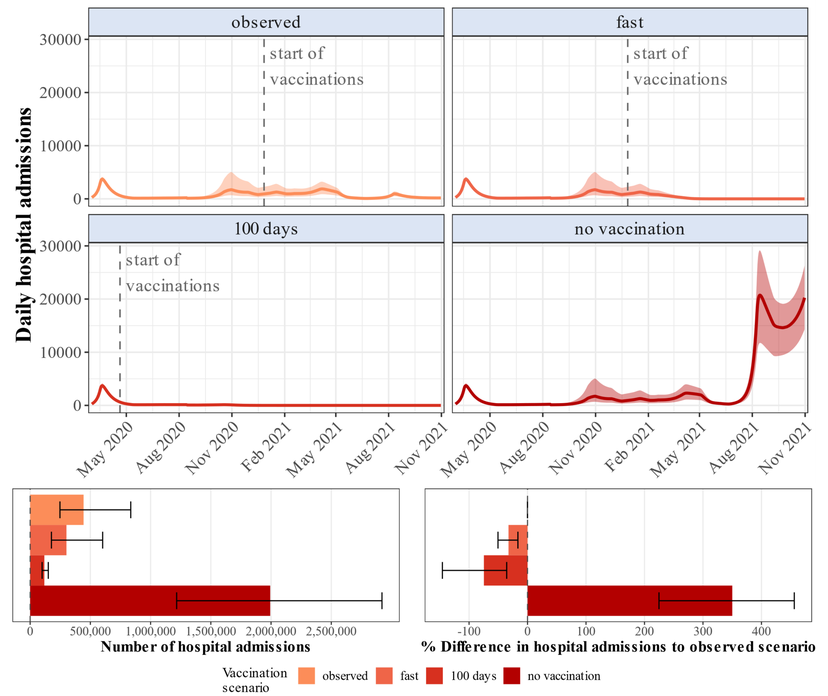

Fig 5: Simulated hospital admissions in France under different vaccination scenarios. Start of vaccinations in the 100-day-scenario was Apr 20, 2020, 100 days after the complete genomic sequence of SARS-CoV-2 was released. In the "fast" scenario, the same start date as observed is assumed, but with a quicker rollout, vaccinating 1% of the population each day. In all scenarios, we assume the same NPI conditions as observed and no waning of vaccination immunity. Compared to the scenario without a vaccine, under the observed scenario, 1.5 millions of hospitalizations (95% PI [1-2] millions) were prevented. Had a vaccine been available within 100 days, an additional 330,000 hospitalizations [646,000-158,000] could have been prevented.

CONCLUSIONS

- All NPIs implemented by the French government **significantly reduced SARS-CoV-2 transmission**.
- The effectiveness of lockdowns decreased over time.
- Curfews were effective, the 6pm curfew more than the 8pm curfew.
- Vaccines were **highly effective against hospitalization** and had some effect against transmission.
- A fast vaccine rollout is essential for reducing hospitalizations.
- NPIs are needed to contain the epidemics if vaccine coverage is low.
- Stringent NPIs and a high vaccination coverage are important to prevent COVID-19 resurgences and control other emerging infectious diseases.

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