Modeling the impact of COVID-19 vaccination for the state of Florida

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“In conclusion …”
Conclusions

- Main benefit will be prevention of death and severe disease among vaccinees
- Vaccination campaign is too little, too late to disrupt 2021 transmission
- Epidemic waves in future years (2023?) can still be prevented by vaccination
- Mutant strains could make spring 2021 much worse
What can vaccines (potentially) do?

● For the vaccinee:
  ○ Reduced mortality
  ○ Reduced symptoms

● For the population:
  ○ Reduced transmission given infection (broken transmission chains)
    ■ Protection of unvaccinated & unsuccessfully vaccinated people
    ■ Elimination/eradication
  ○ Reduced public health, economic, social burden
So you want to know the future ...

We need to understand:

- **Population**
  - Demographics
  - Spatial structure
  - Interaction patterns
  - Behaviors
  - Non-pharmaceutical interventions

- **Pathogen**
  - Outcome probabilities
  - Waiting times

- **Vaccine**
  - Efficacies against the possible outcomes
What we need to know about vaccine efficacy

- $\text{VE}_S$ vaccine efficacy against infection
- $\text{VE}_P$ vaccine efficacy against clinical disease/infection
- $\text{VE}_{SP}$ vaccine efficacy against clinical disease in those infected (primary endpoint in phase III trials)
  - $\text{VE}_{SP} = 1 - (1 - \text{VE}_S) (1 - \text{VE}_P)$
- $\text{VE}_I$ vaccine efficacy against transmission to others/infection
# What we know about VE for three vaccines

<table>
<thead>
<tr>
<th>Platform</th>
<th>Pfizer / BioNTech</th>
<th>Moderna</th>
<th>Astra Zeneca / Oxford U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaccine efficacy against disease $\text{VE}_{\text{SP}}$</td>
<td>95% ($P&lt;0.0001$)</td>
<td>94.1% ($P&lt;0.0001$)</td>
<td>70% (pooled) 90% (low dose) and 61% (standard dose) $P&lt;0.0001$</td>
</tr>
<tr>
<td>Total number of cases, $\text{VE}_{\text{SP}}$ for severe disease</td>
<td>170 cases (8 in vaccine group) 10 severe cases (9 in placebo, 1 in vaccine group)</td>
<td>196 cases 30 severe cases, all in placebo group</td>
<td>131 cases across 2 trials No severe cases in vaccines</td>
</tr>
<tr>
<td>Vaccine efficacy against infection $\text{VE}_S$</td>
<td>??</td>
<td>63% [32 to 80] against asymptomatic infection</td>
<td>59% [1 to 83]) against asymptomatic infection in the LD/SD cohort and 4% [−72 to 46] in the SD/SD group</td>
</tr>
<tr>
<td>Vaccine efficacy against transmission $\text{VE}_I$</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>
How do we measure vaccine impact?

- Direct benefit to vaccinated individuals (~efficacy)
- Indirect benefit to unvaccinated & vaccinated individuals

Scenarios where only direct benefit matters

Counterfactual (No vaccine)

Vaccine only prevents disease

No local transmission
How do we measure vaccine impact?

- Direct benefit to vaccinated individuals (~efficacy)
- Indirect benefit to unvaccinated & vaccinated individuals

Scenarios where only direct benefit matters
How do we measure vaccine impact?

- Direct benefit to vaccinated individuals (~efficacy)
- Indirect benefit to unvaccinated (& vaccinated) individuals

Diagram:

Counterfactual
(No vaccine)

Vaccine prevents
infection
How do we measure vaccine impact?

- Direct benefit to vaccinated individuals (~efficacy)
- Indirect benefit to unvaccinated (& vaccinated) individuals
- Overall benefit = direct benefit + indirect benefit

Best measure of public health impact
Population immunity needed to prevent/shrink an epidemic

Assumes a homogenous, well-mixed population

Natural immunity counts too!
Critical questions

- What amount of natural immunity is in the population?
- How much transmission is really happening?
- What will vaccine roll-out look like?
- What’s going on with the mutants?
Taking a step back:
What do we know about the population?

Homogenous population

Reality
Time-varying factors

Infection detection

Case reporting delay

Death reporting delay
Time-varying factors

CBS.com
Our model
COVID-19 natural history model

- Infections can be
  - Asymptomatic
  - Mild
  - Severe (possibly hospitalized)
  - Critical (possibly receive intensive care)
  - Fatal

- Probabilistic state durations
- Outcome affects detection, does not (directly) affect infectiousness
- Detection probability and lag are time-varying and depend on outcome
- Age- and health-dependent outcome probabilities
- ICU reduces mortality
Natural immunity

- Starting immunity is log-normally distributed
- Wanes exponentially
- Susceptible below threshold
- Dan et al & PHE preprint

Dan et al (2021) Science
DOI: 10.1126/science.abf4063
FL Synthetic Population

- 20.6m people
- 8.9m households
  - compliance score ~ U(0, 1)
- 7.6k schools
- 3.9k long-term-care facilities
- 307 hospitals
- 2.3m other workplaces
  - 590k non-essential
- Also have subpopulations

~10G of RAM, 8 min per year for statewide model
Data sources

- US Census--American Community Survey (household dist. & composition)
- Agency for Healthcare Administration (AHCA; hospital & LTCF locations)
- National Corporation Directory (workplace locations)
- CDC Behavioral Risk Factor Surveillance System (BRFSS; comorbidity survey by county)
- UF Geoplan Center (shapefiles, school locations)
- SafeGraph and Cuebiq (mobility data)
Associations between people and locations

Proximity-based gravity models:

- Allocate students to schools (based on grade-range; enrollment for higher ed)
- Workers to workplaces (workplace size ~ pareto fit to NAICS)
- Households to hospitals (AHCA)
- Inter-household connections (probabilistic based on household size)
Example model household from Miami, FL
Transmission settings

- **Within-household**
  - Complete graph/frequency-dependent
  - Age-specific susceptibility and pathogenicity reduce cases in children

- **Between-household**
  - Interaction network, scales with household size
  - Social distancing compliance reduces contact
  - Households with similar compliance more likely to interact

- **Workplace**
  - Non-essential workplaces close given order
  - Social distancing reduces transmissibility

- **Hospital**
  - Employees and a subset of severe and critically ill patients

- **Long term care facility**
  - Employees and residents
Vaccine assumptions*

- \( V_E_S = 0.6 \)
- \( V_E_P = 0.875 \)
- \( V_E_{SP} = 0.95 \)
- Efficacy occurs after 10 days, is durable

* consistent with data for both mRNA vaccines

Polack et al (2020), NEJM
DOI: 10.1056/NEJMoa2034577
Vaccination campaign assumptions

- Campaign starts at the beginning of 2021
- 50% coverage
- >65-year-olds vaccinated first, then 16- to 64-year-olds
- Two distribution rates:
  - 0.12% of population per day (current rate)
  - 0.3% of population per day (Biden proposal)
No mutant strain

Rt

Case incidence per 10k

Death incidence per 10k

- No Vaccine
- Slower rollout
- Faster rollout
Transmission Process + Observation Process = Reported Data
Effectiveness and cases (deaths, etc.) averted

Effectiveness = 1 - \[\frac{\text{# cases given vac}}{\text{counterfactual # cases}}\]

Cases averted = (counterfactual # cases) - (# cases given vac)
With 50% more infectious mutant strain introduced during Jan 2021
Some important assumptions and limitations

- ~35% cumulative attack rate as of Jan 20, 2021
- NPIs will not change during next ~6 months
- Seasonality is not a major factor
- Vaccine works against mutant strains
Conclusions

- Main benefit will be prevention of death and severe disease among vaccinees.
- Vaccination campaign is too little, too late to disrupt 2021 transmission.
- Epidemic waves in future years (2023?) can still be prevented by vaccination.
- Mutant strains could make spring 2021 much worse.
Thank you!

University of Florida
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University of Michigan
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University of Washington
Betz Halloran

National Corporation Directory

SafeGraph
How many people in Florida remain susceptible*?

- Based on deaths (HIC IFR of 1.15% from Brazeau et al, 29 Oct 2020):
  - 0.90 (95% pred interval: [0.86, 0.94])

As of 12 Jan, 2021
<table>
<thead>
<tr>
<th>Location</th>
<th>Deaths from COVID-19, no. (date)</th>
<th>Inferred infection fatality rate (corrected), %</th>
<th>% of deaths from COVID-19 in people &lt; 70 years</th>
<th>Infection fatality rate in people &lt; 70 years (corrected), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA (10 states)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington, Puget Sound</td>
<td>207 (4 April)</td>
<td>0.43 (0.43)</td>
<td>10 (state, &lt; 60 years)</td>
<td>0.05 (0.05)</td>
</tr>
<tr>
<td>Utah</td>
<td>58 (4 May)</td>
<td>0.08 (0.08)</td>
<td>28 (&lt; 65 years)</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>New York</td>
<td>4146 (4 April)</td>
<td>0.65 (0.65)</td>
<td>34 (state)</td>
<td>0.25 (0.25)</td>
</tr>
<tr>
<td>Missouri</td>
<td>329 (30 April)</td>
<td>0.20 (0.20)</td>
<td>23</td>
<td>0.05 (0.05)</td>
</tr>
<tr>
<td>Florida, south</td>
<td>295 (15 April)</td>
<td>0.25 (0.25)</td>
<td>28 (state)</td>
<td>0.08 (0.08)</td>
</tr>
<tr>
<td>Connecticut</td>
<td>2718 (6 May)</td>
<td>1.54 (1.54)</td>
<td>18</td>
<td>0.31 (0.31)</td>
</tr>
<tr>
<td>Louisiana</td>
<td>806 (11 April)</td>
<td>0.30 (0.30)</td>
<td>32</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>California, San Francisco Bay</td>
<td>321 (1 May)</td>
<td>0.50 (0.50)</td>
<td>25</td>
<td>0.14 (0.14)</td>
</tr>
<tr>
<td>Pennsylvania, Philadelphia</td>
<td>697 (26 April)</td>
<td>0.45 (0.45)</td>
<td>21 (state)</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>Minnesota, Minneapolis</td>
<td>436 (13 May)</td>
<td>0.48 (0.48)</td>
<td>20 (state)</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>USA (California, Bay Area)</td>
<td>12 (22 March)</td>
<td>0.15 (0.12)</td>
<td>25</td>
<td>0.04 (0.03)</td>
</tr>
<tr>
<td>USA (California, Los Angeles)</td>
<td>724 (19 April)</td>
<td>0.20 (0.18)</td>
<td>24 (&lt; 65 years)</td>
<td>0.06 (0.05)</td>
</tr>
<tr>
<td>USA (California, San Francisco)</td>
<td>0 (4 May)</td>
<td>0.00 (0.00)</td>
<td>0</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>USA (California; Santa Clara)</td>
<td>94 (22 April)</td>
<td>0.18 (0.17)</td>
<td>35</td>
<td>0.07 (0.06)</td>
</tr>
<tr>
<td>USA (Idaho, Boise)</td>
<td>14 (24 April)</td>
<td>0.16 (0.13)</td>
<td>14 (Idaho)</td>
<td>0.02 (0.02)</td>
</tr>
<tr>
<td>USA (Georgia)</td>
<td>198 (7 May)</td>
<td>0.44 (0.44)</td>
<td>30</td>
<td>0.15 (0.15)</td>
</tr>
<tr>
<td>USA (Idaho, Blaine county)</td>
<td>5 (19 May)</td>
<td>0.10 (0.08)</td>
<td>14 (Idaho)</td>
<td>0.02 (0.01)</td>
</tr>
<tr>
<td>USA (Indiana)</td>
<td>1099 (30 April)</td>
<td>0.58 (0.46)</td>
<td>24</td>
<td>0.16 (0.13)</td>
</tr>
<tr>
<td>USA (Louisiana, Baton Rouge)</td>
<td>420 (30 July)</td>
<td>0.91 (0.73)</td>
<td>32 (Louisiana)</td>
<td>0.32 (0.25)</td>
</tr>
<tr>
<td>USA (Louisiana, Orleans and Jefferson Parish)</td>
<td>925 (16 May)</td>
<td>1.63 (1.31)</td>
<td>32</td>
<td>0.57 (0.46)</td>
</tr>
<tr>
<td>USA (New York)</td>
<td>18610 (30 April)</td>
<td>0.66 (0.54)</td>
<td>34</td>
<td>0.26 (0.23)</td>
</tr>
<tr>
<td>USA (New York Columbia University Medical Center, New York City and CareMount central laboratory, five New York state counties)</td>
<td>965 (28 March, New York state)</td>
<td>0.15 (0.14)</td>
<td>34</td>
<td>0.06 (0.05)</td>
</tr>
<tr>
<td>USA (New York, Brooklyn)</td>
<td>4894 (19 May)</td>
<td>0.41 (0.33)</td>
<td>34 (New York state)</td>
<td>0.15 (0.14)</td>
</tr>
<tr>
<td>USA (Rhode Island), blood donors</td>
<td>430 (11 May)</td>
<td>1.04 (0.83)</td>
<td>17</td>
<td>0.20 (0.16)</td>
</tr>
</tbody>
</table>
R(t)
(Time-varying reproduction number)

Weekly cases per 10k

Cumulative effectiveness
(Fraction of prevented cases)

Cumulative cases averted
(aka prevented cases)