A Dynamic Prioritization Approach: Breaking the Transmission Chain for Optimal Utilization of Covid-19 Vaccines.

[1]Nidhi Thomas, [2]Neha Thomas and [3]Dr. Elizabeth Thomas

drlizthomas2007@gmail.com
[1]Grade 11, GEMS Our Own English High School, Dubai, UAE
[2]B.Tech CSE, College of Engineering, Guindy, Anna University, Chennai, India
[3]Public Health Dentist, Dubai, UAE

Abstract: The severity of the pandemic and the limited supply of vaccines, calls for a methodical and targeted approach in prioritizing vaccine distribution, with the main focus on breaking the transmission chain, instead of focusing on entire tiers of population groups. Some sections of these groups, which might be static and may not be directly in the transmission chain, can instead continue to be under strict social distancing and isolation protocols that are already in place, until more numbers of vaccines can be produced. The limited supply of vaccines can then be redirected to the sections which are at a high risk of transmission, thus helping to curb disease progression. This strategy must be implemented in conjunction with restrictive Covid protocols that are already in place, in order to shelter vulnerable groups and minimize loss of lives, until more vaccines are made available to reach every section of the population. This comprehensive approach will also ensure that ethical principles are being followed to include the disadvantaged by protecting the vulnerable population groups, while at the same time, methodically targeting the population group sub-sections that are in the high-risk category for spreading the virus and which are also a part of the dynamic and mobile population, mostly responsible for virus transmission. This will control the spread of the outbreak to a certain extent, help bring about the revival of the economy and buy time until more numbers of vaccines can be developed, to vaccinate more than two-thirds of the world's population.

Index Terms:. Dynamic Prioritization, Virus Transmission Chain, Optimal Vaccine Utilization.

INTRODUCTION:

The release of the SARS-CoV-2 vaccines in record time, signals the beginning of a challenging journey to reach the end of a pandemic that has brought the entire world to a standstill over the past year. Prioritizing vaccine distribution, an endlessly debated topic that has brought up complex ethical dilemmas, is now the next important step.

Vaccine developers estimate that they will develop sufficient doses for one third of the world's population by the end of 2021 [1]. While some countries have pre-booked doses, more than 189 countries have joined the COVAX initiative, which assures coverage to at least 20% of the population of participating countries in the first phase [2].

Even presuming a high vaccine efficacy rate, it will take years before the vaccine can bring this pandemic under control [29]. Vaccines alone cannot be relied upon and the importance of mass

testing, contact tracing and physical distancing cannot be over-emphasized [36]. *The* WHO, the CDC (USA) and JCVI (UK) have given guidance based on a values framework and ethical principles [3], [4], [5], [6].

However, if the course of the disease progression is analyzed since the first outbreak, it can be seen that it has affected different population groups with differing degrees of severity. Although research is still ongoing in the study of the transmission and spread of the virus, the current evidence clearly reveals the transmission routes and the impact of breaking the transmission chain to contain the outbreak [7]. This prioritization approach has been divided into two stages, Phase one and Phase Two.

METHODOLOGY-PHASE ONE:

Frontline workers: The utmost priority, as agreed by most expert panels, must be given to all **frontline healthcare** workers. Priority must then be given to **essential services** workers across all groups, in the public domain, for whom social distancing is limited or not possible [26], [42].

The **immuno-compromised** patients across all age groups, and those with chronic diseases that put them at a higher risk of contracting the virus, (other than those in isolated hospital or care home settings), who need to travel to their workplaces, live with extended family or live in crowded areas must be vaccinated in phase one. Pregnant women have been excluded from vaccinations, as clinical trials were not done for this category.

Natural immunity: Studies have shown that the immune memory of the virus persisted for six months in the blood samples of previously infected patients, showing both B cells (humoral or antibody-mediated immunity) and T lymphocytes (cell-mediated immunity) [9], [10], [11]. In another study, George Kassiotis et al. found that roughly 5 percent of the uninfected adult study participants had antibodies that recognized SARS-CoV-2 [10], [11]. Kari Stefansson et al. found in their study that 90% of recovered participants showed antibodies against the virus which peaked in two months and remained in the same level for two more months [11], [12]. A study by Wajnberg et al. found stable antibody levels in recovered patients for three to five months [11], [13]. Greninger et al. at the University of Washington, School of Medicine in Seattle in their study showed statistically significant evidence that neutralizing antibodies acquired during SARS-CoV-2 infection protected previously infected patients against reinfection [14]. These studies show that patients who were **previously infected** with and have recovered from the virus, in the past two months (except frontline workers) can be excluded from Phase one of the vaccination priority until the next phase [22], [34].

Over-crowded urban areas: Rader, Benjamin et al. showed in their study [32] that residents in crowded cities and densely populated urban centers are prone to outbreaks and must be prioritized. This is not seen in uncrowded cities where people stay in their own neighborhoods. This was also seen in a study [33], where the outbreak patterns differed between resource-poor settings and wealthier places, according to a contact-tracing study done in India.

Children and the young adult population: Studies have shown that children not previously infected, showed antibodies in their blood, which probably explained their mild or no symptoms [17], [11]. Children and young adults were less likely to have symptoms and some study results implied that virus transmission spread rapidly from child to child [11], [15]. Although they are the group with a high risk of transmission, children can be excluded from phase one, as clinical trials

have not been completed for them. Till then, strict measures of social distancing, face masks and hand hygiene are to be implemented in schools [16], [8], while all staff and caregivers on the campus who are immuno-compromised and/or are over the age of 60, should be vaccinated. This can be applied to Universities as well.

The elderly population: The elderly in long-term care homes have been given utmost priority in all recommendations. However, with Covid 19 protocols in force now, the healthy elderly populaces who are isolated in care homes are more protected than those in crowded areas. The long-term care home residents can be excluded from the vaccinations in phase one whilst strict Covid19 protocols can be continued and their external caregivers must be vaccinated. An outbreak among University students in Wisconsin [11] spilled into a care home nearby leading to two deaths, making it imperative that strict isolation measures be followed in elderly care homes, allowing contact only with vaccinated caregivers. Likewise, in an outbreak at three childcare centers in Georgia, a CDC Team investigation found that it was an external staff member who was the first known case [19], [18]. On the other hand, a research team in Shanghai, China, found that the greatest risk of transmission was between people who lived together in extended family settings [21], [11]. All persons above 60, who live in extended family settings or who need to commute to workplaces and also those living in crowded, dense housing areas must be included in phase one of vaccinations. A study in [30] highlights another important issue. They predicted that restricted occupancy at super spreader 'points of interest' determined by data collected from sources, was an effective measure to control transmission. In [35], it was determined that infection rates among the disadvantaged racial and socioeconomic groups was higher, due to mobility differences, as these groups were not able to reduce their mobility into crowded areas during the pandemic [35]. This group must be included in phase one, after accounting for the exclusions highlighted earlier.

DISCUSSION:

The current focus should be on slowing down the virus spread, while sheltering vulnerable population groups [20]. This can be achieved by using the limited vaccines available in phase one to target and break the virus transmission chain, while ensuring that all vulnerable and high-risk individuals are protected, until trials ensure vaccine safety for all categories and enough numbers are made available to vaccinate larger sections of the population.

Instead of vaccinating entire levels of population groups, this approach of dynamically prioritizing within a group will ensure that the limited numbers of the vaccine are being used to precision, to ensure that the virus spread is contained, while ensuring ethical guidelines are being considered, by attending to all sections of the population. This idea can be somewhat be understood using the analogy of drip irrigation in areas of severe water shortage.

Analyzing impact to design Phase Two: It is vital to accurately estimate the impact of the vaccine program and this is best done using mathematical models [28]. A combination of mathematical modeling and statistics can be used to study the impact of phase one, and these results can be used to determine the way forward in **Phase Two**. Although the use of Artificial Intelligence is shown to be limited in prediction and tracking of infection, [25] it can be utilized in vaccine prioritization, provided the criteria fed into the algorithm has been decided by policy makers and experts, to ensure ethical concerns are given the right priority.

The UAE Perspective

The United Arab Emirates has implemented timely measures to ensure that the outbreak did not spiral out of control. The UAE has recorded a mortality rate of 0.5 per cent in the pandemic, among the lowest in the world [44]. The UAE has launched the Hope Coalition initiative to facilitate the distribution of 6 billion doses around the world, increasing this capacity to 18 billion by the end of 2021, showing global responsibility [74]. A patent for an Artificial Intelligence-based vaccine priority system has been filed in the UAE, using an inventive method based on the analysis of data collected, to decide who should get vaccinated first in order to halt the spread of the virus [25]

CONCLUSION:

Although a detailed prioritization strategy is not within the scope of this essay, an attempt has been made to highlight how a methodological and scientific approach to prioritize population groups for vaccination.

To put things in perspective, it is apt to quote the news article in the website: The Conversation, published on 3 Sept. 2020, "With a full-scale public health campaign behind it, that will mean prioritizing those who are driving transmission, not those who are most vulnerable. As counterintuitive as such a strategy may appear, plenty of evidence shows this would be the right approach" [40].

REFERNCES & BIBLIOGRAPHY:

1. "How COVID Vaccines Are Being Divvied up around the World." *Nature*, www.nature.com/articles/d41586-020-03370-6?error=cookies_not_supported&code=3320c581-fac3-4520-a273-df4a0fa11761.
2. "How COVID Vaccines Are Being Divvied up around the World." *Nature*, www.nature.com/articles/d41586-020-03370-6?error=cookies_not_supported&code=3320c581-fac3-4520-a273-df4a0fa11761.
3. World Health Organization. "WHO SAGE Values Framework for the Allocation and Prioritization of COVID-19 Vaccination, 14 September 2020." *Www.Who.Int*, 14 Sept. 2020, apps.who.int/iris/handle/10665/334299.
4. World Health Organization. "WHO SAGE Values Framework for the Allocation and Prioritization of COVID-19 Vaccination, 14 September 2020." *Www.Who.Int*, 14 Sept. 2020, apps.who.int/iris/handle/10665/334299.
5. "COVID-19 and Your Health." *Centers for Disease Control and Prevention*, 11 Feb. 2020, www.cdc.gov/coronavirus/2019-ncov/vaccines/recommendations-process.html.
6. "Covid 19 Vaccination Program." *Www.Cdc.Gov*, www.cdc.gov/vaccines/imz-managers/downloads/COVID-19-Vaccination-Program-.
7. "Transmission of SARS-CoV-2: Implications for Infection Prevention Precautions." *Www.Who.Int*, 9 July 2020, www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions.
8. Fontanet, Arnaud, and Simon Cauchemez. "COVID-19 Herd Immunity: Where Are We?" Nature Reviews Immunology, 9 Sept. 2020, www.nature.com/articles/s41577-020-00451-5?error=cookies_not_supported&code=c187237e-9cbf-47ae-8a2b-c8ed18ab65b9.

9. Dan, Jennifer. “Immunological Memory to SARS-CoV-2 Assessed for Greater than Six Months after Infection.” BioRxiv, 1 Jan. 2020, www.biorxiv.org/content/10.1101/2020.11.15.383323v1.

10. Ng, Kevin. “Preexisting and de novo humoral immunity to SARS-CoV-2 in humans”, sciencemag.org, https://science.sciencemag.org/content/370/6522/1339
11. Nature Editorial. “COVID Research Updates: A Coronavirus Vaccine Shows Lasting Benefit.” Nature, www.nature.com/articles/d41586-020-00502-w?error=cookies_not_supported&code=9a4d8d49-5c02-487d-968b-381c7f4ebcb3.
12. Gudbjartsson, Daniel F. et al. ”Humoral Immune Response to SARS-CoV-2 in Iceland” 29 Oct 2020, https://www.nejm.org/doi/10.1056/NEJMoa2026116
13. Wajnberg, Ania. “Robust Neutralizing Antibodies to SARS-CoV-2 Infection Persist for Months.” Science, 4 Dec. 2020, science.sciencemag.org/content/370/6521/1227.
14. “COVID-19 News Update for August 18, 2020.” The Huddle, 19 Aug. 2020, huddle.uwmedicine.org/news/covid-19-news-update-aug-18-2020.
15. Hurst, Jillian. “SARS-CoV-2 Infections Among Children in the Biospecimens from Respiratory Virus-Exposed Kids (BRAVE Kids) Study.” MedRxiv, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.08.18.20166835v2.
16. Miskin, Chen Stein-Zamir|Nitza Abramson|Hanna Shoob|Erez Libal|Menachem Bitan|Tanya Cardash|Refael Cayam|Ian. “Eurosurveillance | A Large COVID-19 Outbreak in a High School 10 Days after Schools’ Reopening, Israel, May 2020.” EuroSurveillance, 23 July 2020, www.eurosurveillance.org/content/10.2807/1560-7917.ES.2020.25.29.2001352.
17. Ng, Kevin. “Preexisting and de Novo Humoral Immunity to SARS-CoV-2 in Humans.” Science, 5 Nov. 2020, science.sciencemag.org/content/early/2020/11/05/science.abe1107.
18. Persad, Govind J. “Fairly Prioritizing Groups for Access to COVID-19 Vaccines.” Infectious Diseases | JAMA | JAMA Network, 27 Oct. 2020, jamanetwork.com/journals/jama/fullarticle/2770684.
19. Lopez, Adriana. “Transmission Dynamics of COVID-19 Outbreaks Associated ...” Centers for Disease Control and Prevention, 17 Sept. 2020, www.cdc.gov/mmwr/volumes/69/wr/mm6937e3.htm?s_cid=mm6937e3_w.
20. Brodin, Petter. “Why Is COVID-19 so Mild in Children?” PubMed, pubmed.ncbi.nlm.nih.gov/32212348. Accessed 10 Dec. 2020.
21. Sun, Kaiyuan. “Transmission Heterogeneities, Kinetics, and Controllability of SARS-CoV-2.” Science, 23 Nov. 2020, science.sciencemag.org/content/early/2020/11/23/science.abe2424.
22. Ladhani, Shamez. “High Prevalence of SARS-CoV-2 Antibodies in Care Homes Affected by COVID-19; a Prospective Cohort Study in England.” MedRxiv, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.08.10.20171413v1.
23. “CDC Advisory Panel Takes First Shot at Prioritizing Who Gets the First Shots of COVID-19 Vaccines.” Science | AAAS, 2 Dec. 2020, www.sciencemag.org/news/2020/12/cdc-advisory-panel-takes-first-shot-prioritizing-who-gets-first-shots-covid-19-vaccines.
24. Gokulan, Dhanusha. “Coronavirus: UAE Announces Covid-19 Vaccine Distribution Plan; Issues National Day Advisory.” Khaleej Times, 30 Nov. 2020, www.khaleejtimes.com/coronavirus-pandemic/coronavirus-uae-announces-covid-19-vaccine-distribution-plan-issues-national-day-advisory.

25. Fenster, Maier, and Gal Ehrlich. “First Israeli Patent for Vaccine Priority System Filed in the UAE | IAM.” Www.Iam-Media.Com, www.iam-media.com/first-israeli-patent-vaccine-priority-system-filed-in-the-uae.

26. Buckner, Jack. “Dynamic Prioritization of COVID-19 Vaccines When Social Distancing Is Limited for Essential Workers.” MedRxiv, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.09.22.20199174v4.
27. Guo, Eileen. “How the US, UK, and China Are Planning to Roll out Vaccines.” MIT Technology Review, 8 Dec. 2020, www.technologyreview.com/2020/12/04/1013183/us-uk-and-china-covid-vaccine-who-gets-priority-decision.
28. Scherer, Almut. “Mathematical Models of Vaccination.” PubMed, 2002, pubmed.ncbi.nlm.nih.gov/12176860/.
29. “COVID-19 Vaccine Predictions: Using Mathematical Modelling and Expert.” Center For Global Development, www.cgdev.org/publication/covid-19-vaccine-predictions.
30. Chang, Serina, et al. “Mobility Network Models of COVID-19 Explain Inequities and Inform Reopening.” Nature, 10 Nov. 2020, www.nature.com/articles/s41586-020-2923-3?error=cookies_not_supported&code=6f69834e-c0aa-413d-903d-2f35867ad0e6.
31. Mandavilli, Apoorva. “You May Have Antibodies After Coronavirus Infection. But Not for Long.” The New York Times, 26 July 2020, www.nytimes.com/2020/06/18/health/coronavirus-antibodies.html.
32. Rader, Benjamin, et al. “Crowding and the Shape of COVID-19 Epidemics.” Nature Medicine, 5 Oct. 2020, www.nature.com/articles/s41591-020-1104-0?error=cookies_not_supported&code=f85c7a98-66b8-4b1c-8c72-a8a1a8e31c05.
33. Laxminarayan, Ramanan. “Epidemiology and Transmission Dynamics of COVID-19 in Two Indian States.” Science, 6 Nov. 2020, science.sciencemag.org/content/370/6517/691.
34. Vivek Gupta, Rahul C Bhoyar, Abhinav Jain, Saurabh Srivastava, Rashmi Upadhayay, Mohamed Imran, Bani Jolly, Mohit Kumar Divakar, Disha Sharma, Paras Sehgal, Gyan Ranjan, Rakesh Gupta, Vinod Scaria, Sridhar Sivasubbu, Asymptomatic Reinfection in 2 Healthcare Workers From India With Genetically Distinct Severe Acute Respiratory Syndrome Coronavirus 2, Clinical Infectious Diseases, , ciaa1451, https://doi.org/10.1093/cid/ciaa1451
35. Adam, Dillon, et al. “Clustering and Superspreading Potential of SARS-CoV-2 Infections in Hong Kong.” Nature Medicine, 17 Sept. 2020, www.nature.com/articles/s41591-020-1092-0?error=cookies_not_supported&code=eeecd1fa-f3f5-404b-a406-c0c0d302520a.
36. Ferretti, Luca. “The Timing of COVID-19 Transmission.” MedRxiv, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.09.04.20188516v2.
37. Klepac, Petra. “What We Scientists Have Discovered about How Each Age Group Spreads Covid-19.” The Guardian, 1 July 2020, www.theguardian.com/commentisfree/2020/mar/17/scientists-age-groups-covid-19-workplaces-shops-restaurants.
38. Zimmer, Katarina. “Why R0 Is Problematic for Predicting COVID-19 Spread.” The Scientist Magazine®, 8 July 2020, www.the-scientist.com/features/why-r0-is-problematic-for-predicting-covid-19-spread-67690.
39. Goldman, Dana, et al. “Why COVID-19 Vaccines Need to Prioritize ‘Superspreaders.’” The Conversation, 3 Sept. 2020, theconversation.com/why-covid-19-vaccines-need-to-prioritize-superspreaders-145232.

40. "Why COVID-19 Vaccines Need to Prioritize 'Superspreaders.'" The Conversation, 3 Sept. 2020, theconversation.com/why-covid-19-vaccines-need-to-prioritize-superspreaders-145232.
41. Paul Fine, Ken Eames, David L. Heymann, "Herd Immunity": A Rough Guide, Clinical Infectious Diseases, Volume 52, Issue 7, 1 April 2011, Pages 911–916, https://doi.org/10.1093/cid/cir007
42. Bubar, Kate. "Model-Informed COVID-19 Vaccine Prioritization Strategies by Age and Serostatus." MedRxiv, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.09.08.20190629v2.full.
43. Klepac, Petra. "What We Scientists Have Discovered about How Each Age Group Spreads Covid-19." The Guardian, 1 July 2020, www.theguardian.com/commentisfree/2020/mar/17/scientists-age-groups-covid-19-workplaces-shops-restaurants.
44. "Coronavirus UAE reports 1121 COVID 19 cases." 2020 Galadari Printing and Publishing LLC. All Rights Reserved., www.khaleejtimes.com/coronavirus-pandemic/coronavirus-uae-reports-1121-covid-19-cases-1295-recoveries-5-death.
45. Flanagan, Ben. "Saudi Arabia Using AI to Allocate Covid-19 Vaccines." WIRED Middle East, 24 Nov. 2020, wired.me/science/health/who-gets-the-vaccine-first-in-saudi-arabia-ai-has-the-answer.
46. Ramirez, Vanessa Bates. "What Is R0? Gauging Contagious Infections." *Healthline*, 20 Apr. 2020, www.healthline.com/health/r-nought-reproduction-number#how-its-calculated.
47. "COVID-19 Herd Immunity: Where Are We?" *Nature Reviews Immunology*, 9 Sept. 2020, www.nature.com/articles/s41577-020-00451-5?error=cookies_not_supported&code=1399cdf6-9d30-4a1f-bec0-53879cebfc48.
48. "Challenges in Creating Herd Immunity to SARS-CoV-2 Infection by Mass Vaccination." *ScienceDirect*, 21 Nov. 2020, linkinghub.elsevier.com/retrieve/pii/S0140673620323187.
49. Rader, Benjamin, et al. "Crowding and the Shape of COVID-19 Epidemics." *Nature Medicine*, 5 Oct. 2020, www.nature.com/articles/s41591-020-1104-0?error=cookies_not_supported&code=f85c7a98-66b8-4b1c-8c72-a8a1a8e31c05.
50. Digital, Traffic. "COVID-19." *DOHGOV*, www.doh.gov.ae/covid-19.
51. Arun, T. "View: How to Prioritise Covid-19 Vaccine Recipients." *The Economic Times*, 27 May 2020, economictimes.indiatimes.com/news/politics-and-nation/view-distributing-the-vaccine/articleshow/76013726.cms.
52. Team, Dna Web. "By February, Half of India's Population Could Become COVID-19 Infected." *DNA India*, 20 Oct. 2020, www.dnaindia.com/india/report-by-february-half-of-india-s-population-could-become-covid-19-infected-2851012.
53. "COVID-19 Vaccine Tracker." *RAPS*, www.raps.org/news-and-articles/news-articles/2020/3/covid-19-vaccine-tracker.
54. De, Abhishek. "Explained: How Effective Are the Top Vaccines for Covid-19, and When Will They Be Available?" *The Indian Express*, 26 Nov. 2020, indianexpress.com/article/explained/covid-vaccines-effectiveness-pfizer-moderna-oxford-when-will-they-be-available-7058464.
55. Zimmer, Katarina. "Why R0 Is Problematic for Predicting COVID-19 Spread." *The Scientist Magazine®*, 8 July 2020, www.the-scientist.com/features/why-r0-is-problematic-for-predicting-covid-19-spread-67690.

56. "Experts Warn Against Vaccinating Frontline Health Workers" *Www.Newindianexpress.Com*, www.newindianexpress.com/states/kerala/2020/nov/28/experts-warn-against-vaccinating-frontline-health-workers-first-2228993.html.

57. "Why COVID-19 Vaccines Need to Prioritize 'Superspreaders.'" *The Conversation*, 3 Sept. 2020, theconversation.com/why-covid-19-vaccines-need-to-prioritize-superspreaders-145232.
58. Report, Web. "Is India Closer to Herd Immunity against Covid-19?" *Khaleej Times*, 19 Aug. 2020, www.khaleejtimes.com/world/india/is-india-closer-to-herd-immunity-against-covid-19.
59. "Herd Immunity and COVID-19 (Coronavirus): What You Need to Know." *Mayo Clinic*, 6 June 2020, www.mayoclinic.org/diseases-conditions/coronavirus/in-depth/herd-immunity-and-coronavirus/art-20486808.
60. "A 'herd Mentality' Can't Stop the COVID-19 Pandemic. Neither Can a Weak Vaccine." *Science*, 2 Oct. 2020, www.nationalgeographic.com/science/2020/10/natural-herd-immunity-mentality-cannot-stop-coronavirus-weak-vaccine-cvd.
61. "How COVID Vaccines Are Being Divvied up around the World." *Nature*, www.nature.com/articles/d41586-020-03370-6?error=cookies_not_supported&code=122c3bb8-dadb-44ee-93ed-9efec88e29b1.
62. "Implementation of This Guidance during a Future Pandemic | Pandemic Influenza (Flu) | CDC." *CDCGOV*, www.cdc.gov/flu/pandemic-resources/national-strategy/planning-guidance/implementation.html.
63. "508 Accessibility Text for Tables and Figures | Pandemic Influenza (Flu) | CDC." *CDCGOV*, www.cdc.gov/flu/pandemic-resources/national-strategy/planning-guidance/guidance_508.html#table-1.
64. National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Population Health and Public Health Practice; Board on Health Sciences Policy; Committee on Equitable Allocation of Vaccine for the Novel Coronavirus. "Summary - Framework for Equitable Allocation of COVID-19 Vaccine - NCBI Bookshelf." *NCBI*, 2 Oct. 2020, www.ncbi.nlm.nih.gov/books/NBK564086.
65. "Annex A: COVID-19 Vaccine and Health Inequalities: Considerations for Prioritisation and Implementation." *GOV.UK*, 3 Dec. 2020, www.gov.uk/government/publications/priority-groups-for-coronavirus-covid-19-vaccination-advice-from-the-jcvi-2-december-2020/annex-a-covid-19-vaccine-and-health-inequalities-considerations-for-prioritisation-and-implementation.
66. "Annex A: COVID-19 Vaccine and Health Inequalities: Considerations for Prioritisation and Implementation." *GOV.UK*, 3 Dec. 2020, www.gov.uk/government/publications/priority-groups-for-coronavirus-covid-19-vaccination-advice-from-the-jcvi-2-december-2020/annex-a-covid-19-vaccine-and-health-inequalities-considerations-for-prioritisation-and-implementation.
67. Abu-Raya, Bahaa. "Challenges in Evaluating SARS-CoV-2 Vaccines during the COVID-19 Pandemic." *CMAJ*, 24 Aug. 2020, www.cmaj.ca/content/192/34/E982.
68. "Challenges in Evaluating SARS-CoV-2 Vaccines during the COVID-19 Pandemic." *CMAJ*, 24 Aug. 2020, www.cmaj.ca/content/192/34/E982.

69. Goodnough, Abby, and Jan Hoffman. "The Elderly vs. Essential Workers: Who Should Get the Coronavirus Vaccine First?" *The New York Times*, 5 Dec. 2020, www.nytimes.com/2020/12/05/health/covid-vaccine-first.html.
70. *Science | AAAS*, 2 Dec. 2020, www.sciencemag.org/news/2020/12/cdc-advisory-panel-takes-first-shot-prioritizing-who-gets-first-shots-covid-19-vaccines.
71. "How the U.K. Plans to Lead the World in Covid Vaccination" *Www.Bloomberg.Com*, www.bloomberg.com/tosv2.html?vid=&uuid=a3e475f0-3b16-11eb-a134-e5eddc271b93&url=L2dyYXBoaWNzLzIwMjAtdWstdmFjY2luZS1sb2dpc3RpY3Mv.
72. "Priority Groups for Coronavirus (COVID-19) Vaccination: Advice from the JCVI, 2 December 2020." *GOV.UK*, 3 Dec. 2020, www.gov.uk/government/publications/priority-groups-for-coronavirus-covid-19-vaccination-advice-from-the-jcvi-2-december-2020/priority-groups-for-coronavirus-covid-19-vaccination-advice-from-the-jcvi-2-december-2020.
73. Banerjea, Aparna. "Expert Panel Suggests Who Will Be on Priority List for Covid Vaccines in India." *Mint*, 8 Dec. 2020, www.livemint.com/news/india/who-will-be-on-priority-list-for-covid-vaccines-in-india-what-expert-panel-suggests-11607429290362.html.
74. "NCEMA UAE (@NCEMAUAE) | Twitter." *NCEMA UAE*, twitter.com/NCEMAUAE?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1333427424965619713%7Ctwgr%5E%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fwww.khaleejtimes.com%2Fcoronavirus-pandemic%2Fcoronavirus-uae-announces-covid-19-vaccine-distribution-plan-issues-national-day-advisory.
75. "Dynamic Prioritization of COVID-19 Vaccines When Social Distancing Is Limited for Essential Workers." *PubMed Central (PMC)*, www.ncbi.nlm.nih.gov/pmc/articles/PMC7523157.
76. Guo, Eileen. "How the US, UK, and China Are Planning to Roll out Vaccines." *MIT Technology Review*, 8 Dec. 2020, www.technologyreview.com/2020/12/04/1013183/us-uk-and-china-covid-vaccine-who-gets-priority-decision.
77. "COVID-19 Vaccine Tracker." *RAPS*, www.raps.org/news-and-articles/news-articles/2020/3/covid-19-vaccine-tracker.
78. "How to Choose the Best Types of Charts For Your Data." *Venngage*, 19 Oct. 2020, venngage.com/blog/how-to-choose-the-best-charts-for-your-infographic.
79. Zanettini, Claudio. "Influenza Vaccination and COVID19 Mortality in the USA." *PubMed*, 26 June 2020, pubmed.ncbi.nlm.nih.gov/32607525.
80. Sllloyd. "Sllloyd/Vaccine_predictions." *GitHub*, github.com/sllloyd/vaccine_predictions.
81. Clemente-Suárez, Vicente Javier. "Dynamics of Population Immunity Due to the Herd Effect in the COVID-19 Pandemic." *MDPI*, www.mdpi.com/2076-393X/8/2/236.
82. Leonhardt, David. "The Vaccine as Fire Hose." *The New York Times*, 8 Dec. 2020, www.nytimes.com/2020/12/08/briefing/vaccine-don-gable-your-tuesday-briefing.html.
83. Pinarunal. "An Essay on 'Covid-19 Pandemic' by Prof. Dr. Mustafa Asim Safak." *COVID-19 HUB*, 22 May 2020, covid19.tabipacademy.com/2020/05/22/an-essay-on-covid-19-pandemic-by-prof-dr-mustafa-asim-safak.
84. Chow, Denise. "Should People Who Recovered from Covid Get Vaccinated?" *NBC News*, 3 Dec. 2020, www.nbcnews.com/science/science-news/should-people-who-recovered-covid-get-vaccinated-n1249766.

85. Robertson, Adi. “The Best Graphs and Data for Tracking the Coronavirus Pandemic.” *The Verge*, 2 Apr. 2020, www.theverge.com/2020/4/2/21201832/novel-coronavirus-covid-19-best-graphs-tracking-data.
86. “COVID-19 Map.” *Johns Hopkins Coronavirus Resource Center*, coronavirus.jhu.edu/map.html.
87. CSSEGISandData. “CSSEGISandData/COVID-19.” *GitHub*, github.com/CSSEGISandData/COVID-19
88. Oster, Alexandra. “Transmission Dynamics by Age Group in COVID-19 ...” *Centers for Disease Control and Prevention*, 15 Oct. 2020, www.cdc.gov/mmwr/volumes/69/wr/mm6941e1.htm.
89. “DEFINE_ME.” *Scott Halperin*, secure.jbs.elsevierhealth.com/action/cookieAbsent?code=null. Accessed 10 Dec. 2020.
90. Lowndes, C. “Role of Core and Bridging Groups in the Transmission Dynamics of HIV and STIs in Cotonou, Benin, West Africa.” *Sexually Transmitted Infections*, 1 Apr. 2002, sti.bmj.com/content/78/suppl_1/i69.
91. “The Territorial Impact of COVID-19: Managing the Crisis across Levels of Government.” *OECD*, www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-across-levels-of-government-d3e314e1.
92. Block, Per, et al. “Social Network-Based Distancing Strategies to Flatten the COVID-19 Curve in a Post-Lockdown World.” *Nature Human Behaviour*, 4 June 2020, www.nature.com/articles/s41562-020-0898-6?error=cookies_not_supported&code=f0bedaf7-c506-4375-b338-a8b16d77f79e.
93. “Human Rights Dimensions of COVID-19 Response.” *Human Rights Watch*, 28 Oct. 2020, www.hrw.org/news/2020/03/19/human-rights-dimensions-covid-19-response.
94. Klepac, Petra. “What We Scientists Have Discovered about How Each Age Group Spreads Covid-19.” *The Guardian*, 1 July 2020, www.theguardian.com/commentisfree/2020/mar/17/scientists-age-groups-covid-19-workplaces-shops-restaurants.
95. “Cambridge Perspectives: Julia Gog and the BBC Pandemic Project | Features: Faculty Insights.” *Julia Gog*, www.maths.cam.ac.uk/features/cambridge-perspectives-julia-gog-and-bbc-pandemic-project.
96. Aschwanden, Christie, and Christie Aschwanden. “How ‘Superspreading’ Events Drive Most COVID-19 Spread.” *Scientific American*, 23 June 2020, www.scientificamerican.com/article/how-superspreading-events-drive-most-covid-19-spread1.
97. Stevens, Harry. “Why Outbreaks like Coronavirus Spread Exponentially, and How to ‘Flatten the Curve.’” *Washington Post*, 14 Mar. 2020, www.washingtonpost.com/graphics/2020/world/corona-simulator.
98. “- The.” *Washington Post*, www.washingtonpost.com/graphics/2020/health/coronavirus-how-epidemics-spread-and-end/?tid=graphics-story.
99. Chang, Serina, et al. “Mobility Network Models of COVID-19 Explain Inequities and Inform Reopening.” *Nature*, 10 Nov. 2020, www.nature.com/articles/s41586-020-2923-3?error=cookies_not_supported&code=82833a72-4fcd-433c-abfd-e0e470de5dc2.
100. Karin, Omer. “Cyclic Exit Strategies to Suppress COVID-19 and Allow Economic Activity.” *MedRxiv*, 1 Jan. 2020, www.medrxiv.org/content/10.1101/2020.04.04.20053579v4.

101. Betsch, Cornelia, et al. “On the Benefits of Explaining Herd Immunity in Vaccine Advocacy.” *Nature Human Behaviour*, 6 Mar. 2017, www.nature.com/articles/s41562-017-0056?error=cookies_not_supported&code=055c96a3-fbe1-45e8-8295-242f1f48c4d1.