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Mathematical Modeling for Infectious Disease Planning

Review of articles on modeling interventions

A: Akinwande, N. I., Ashezua, T. T., Gweryina, R. I., Somma, S. A., Oguntolu, F. A., Usman, A., ... & Shehu, M. D. (2022). Mathematical model of COVID-19 transmission dynamics incorporating booster vaccine program and environmental contamination. Heliyon, 8(11).

> Heliyon. 2022 Nov 9;8(11):e11513. doi: 10.1016/j.heliyon.2022.e11513. eCollection 2022 Nov.

Mathematical model of COVID-19 transmission dynamics incorporating booster vaccine program and environmental contamination

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In this section, we are interested in examining the optimal strategies of ending COVID-19 pandemic. This is possible by introducing the following controls to the model (3)

- u_1: Prevention strategy aimed at inhibiting the total virus transmission from latent, infected, dead bodies and pathogens via public health advocacy for anti-open defecation, social distancing and wearing of face masks in public places
- u_2: Booster vaccine control program targeted at ensuring that primary vaccinated people attain herd immunity to COVID-19 pandemic
- u_3: Intense medical care through isolation for the infected people
- u_4: Disinfecting or fumigating of surfaces and dead bodies before burial to avoid environmental transmission.

6.1.1. Strategy A In this strategy, the combination of booster vaccine program (u_2) and intense medical care (isolation program) (u_3) is used without fumigation of surfaces and dead bodies ($u_4 = 0$). The dynamics of latent COVID-19, Infectious, dead bodies and corona virus pathogens are given in Fig. 4. Figs. 4(a) and 4(b) show that booster vaccine and isolation for latent and infected COVID-19 controls provide a significant reduction in latent COVID-19 and infectious populations compared to having no controls. Similar scenarios were also observed in the dynamics of the dead and pathogens which is lower as compared to the situation when implemented without controls in Figs. 4(c) and 4(d). This result is consistent with the outcome as in the work of [25]. We noted however in Figs. 4(a)- 4(c) that the infected compartments (Latent and infectious) turn to be stable after 50 days. Thus, the number of death cases after 50 days remains constant through out. The profile of optimal controls u_2^* and u_3^* is depicted in Fig. 5. Booster vaccine program and isolation could be implemented intensively for 300 days before declining. This strategy however lacks the capacity to curtail the pandemic completely as the result shows in Fig. 4.

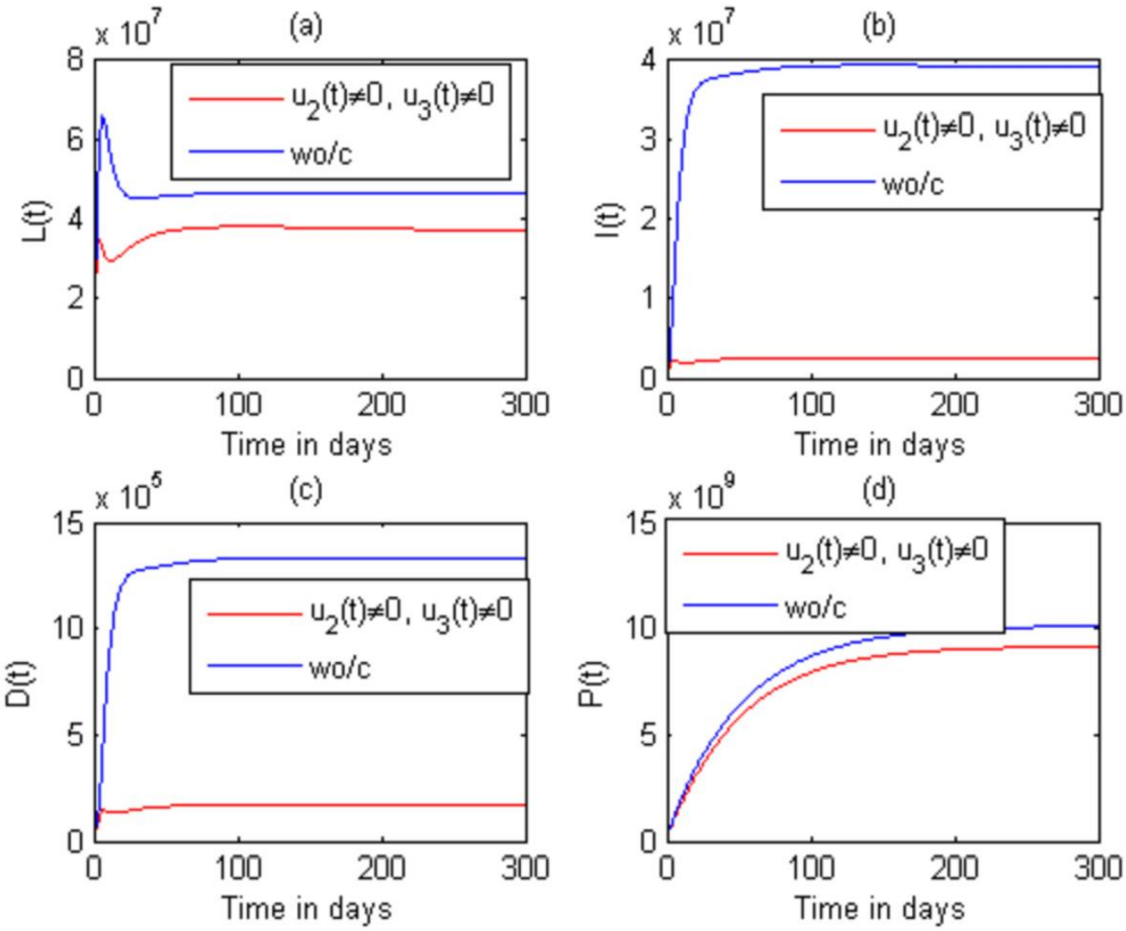

Fig. 4. Dynamics of (a) latent, (b) infectious, (c) dead bodies and (d) corona virus pathogens using strategy A. Note that wo/c represents without control.

B. Ofori, S. K., Schwind, J. S., Sullivan, K. L., Chowell, G., Cowling, B. J., & Fung, I. C. H. (2023). Age-Stratified Model to Assess Health Outcomes of COVID-19 Vaccination Strategies, Ghana. Emerging Infectious Diseases, 29(2), 360.

Age-Stratified Model to Assess Health Outcomes of COVID-19 Vaccination Strategies, Ghana

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We assessed the effect of various COVID-19 vaccination strategies on health outcomes in Ghana by using an age-stratified compartmental model. We stratified the population into 3 age groups: <25 years, 25–64 years, and ≥65 years. We explored 5 vaccination optimization scenarios using 2 contact matrices, assuming that 1 million persons could be vaccinated in either 3 or 6 months. We assessed these vaccine optimization strategies for the initial strain, followed by a sensitivity analysis for the Delta variant. We found that vaccinating persons <25 years of age was associated with the lowest cumulative infections for the main matrix, for both the initial strain and the Delta variant. Prioritizing the elderly (≥65 years of age) was associated with the lowest cumulative deaths for both strains in all scenarios. The consensus between the findings of both contact matrices depended on the vaccine rollout period and the objective of the vaccination program.

Table 2. Scenario analysis of outcomes in the total population under various vaccination scenarios, using the main matrix method for the initial strain, Ghana

Vaccine prioritization by age group, y	Scenario, % infections					
	500,000 vaccinated in 3 mo	500,000 vaccinated in 6 mo	1 million vaccinated in 3 mo	1 million vaccinated in 6 mo	2 million vaccinated in 3 mo	2 million vaccinated in 6 mo
Symptomatic infections at peak						
Only ≥65	7.22	7.24	7.19	7.22	7.16	7.19
25–64	7.09	7.17	6.92	7.09	6.61	6.92
<25	7.01	7.13	6.75	7.01	6.26	6.75
<65	7.03	7.15	6.81	7.03	6.37	6.81
Same rate across age groups	7.04	7.15	6.83	7.04	6.40	6.83
Cumulative infections						
Only ≥65	172.88	173.50	172.09	172.88	171.33	172.09
25 –64	170.80	172.57	167.44	170.80	161.00	167.44
<25	170.04	172.20	165.76	170.04	157.17	165.76
<65	170.28	172.43	166.19	170.28	158.20	166.19
Same rate across age groups	170.41	172.39	166.44	170.41	158.51	166.44
Deaths						
Only ≥65	0.18	0.19	0.17	0.18	0.17	0.17
25–64	0.19	0.19	0.19	0.19	0.18	0.19
<25	0.19	0.19	0.19	0.19	0.18	0.19
<65	0.19	0.19	0.19	0.19	0.18	0.19
Same rate across age groups	0.19	0.19	0.19	0.19	0.18	0.19

Three outcomes were observed: percent of symptomatic infections at the peak, percent of cumulative infections at the end of the simulation (500 days), and percent cumulative deaths at the end of the simulations. The outcomes of the optimization strategies were compared for each scenario of vaccine availability and rollout speed.

3. Kinyili, M., Munyakazi, J. B., & Mukhtar, A. Y. (2022). To use face masks or not after COVID-19 vaccination? An impact analysis using mathematical modeling. Frontiers in Applied Mathematics and Statistics, 8, 872284.

To Use Face Masks or Not After COVID-19 Vaccination? An Impact Analysis Using Mathematical Modeling

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The question of whether to drop or to continue wearing face masks especially after being vaccinated among the public is controversial. This is sourced from the efficacy levels of COVID-19 vaccines developed, approved, and in use. We develop a deterministic mathematical model that factors in a combination of the COVID-19 vaccination program and the wearing of face masks as intervention strategies to curb the spread of the COVID-19 epidemic. We use the model specifically to assess the potential impact of wearing face masks, especially by the vaccinated individuals in combating further contraction of COVID-19 infections. Validation of the model is achieved by performing its goodness of fit to the Republic of South Africa's reported COVID-19 positive cases data using the Maximum Likelihood Estimation algorithm implemented in the fitR package. We first consider a scenario where the uptake of the vaccines and wearing of the face masks, especially by the vaccinated individuals is extremely low. Second, we consider a scenario where the uptake of the vaccines and wearing of the face masks by people who are vaccinated is relatively high. Third, we consider a scenario where the uptake of the vaccines and wearing of the face masks by the vaccinated individuals is on an upward trajectory. Findings from scenario one and scenario two, respectively, indicate a highly surging number of infections and a low recorded number of infections. For scenario three, it shows that the increased extent of wearing of the face masks by the vaccinated individuals at increasing levels of vaccine and face mask average protection results in a highly accelerated decrease in COVID-19 infections. However, wearing face masks alone also results in the reduction of the peak number of infections at increasing levels of face mask efficacy though the infections delay clearing.

FIGURE 5. (A) Trajectory of the symptomatic infections for the model (Equations 2–8) when the uptake of the COVID-19 vaccines and the use of face masks by the vaccinated is relatively high (80%). (B) Trajectory of the asymptomatic infections for the model (Equations 2–8) when the uptake of the COVID-19 vaccines and the use of face masks by the vaccinated is relatively high (80%). (C) Trajectory of the latent cases for the model (Equations 2–8) when the uptake of the COVID-19 vaccines and the use of face masks by the vaccinated is relatively high (80%). Trajectory of the symptomatic, asymptomatic, and latent classes of the model (Equations 2–8) when the uptake of the COVID-19 vaccines and the use of face masks by the vaccinated is relatively high (80%).