Dynamical analysis of a COVID-19 epidemic model with social confinement and acquired immunity loss

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Abstract. Depending on the distinction between the infected individuals whether they have been diagnosed or not and the severity of their symptoms, a SIDARTHE model has been presented to explore the effectiveness of tracking and social distancing in the spread of the Covid-19. By introducing acquired immunity loss to this model, we aim to analyze the influence of the decline of immunity on the propagation of the epidemic. We obtain the basic reproduction number by the generation matrix method, and analyze the global stability of the disease-free equilibrium and the endemic equilibrium by Lyapunov-LaSalle techniques and graph theory. And then we fit the available COVID-19 data to predict the epidemic evolution in Brazil. Our simulation results and the sensitivity analysis suggest that the infection coefficient and the decline rate in the acquired immunity both are important factors that influence the control of the pandemic. These findings should be helpful for policy-makers to choose suitable social-distancing and immunity strategies.

Introduction

Various predictive mathematical models for the COVID-19 epidemic have been presented. Particularly, Giordano et.al.[1] proposed a model of eight stages of infection: susceptible(S), infected(I), diagnosed(D), ailing(A), recognized(R), threatened(T), healed(H) and extinct(E), and found that non-diagnosed individuals are more likely to spread the infection than diagnosed ones, since the latter are typically isolated. The distinction between the diagnosed and non-diagnosed individuals helps to explain misperceptions of the seriousness of the epidemic phenomena. Nevertheless, they omitted the impact of the acquired immunity loss, that is, they did not take the probability rate of becoming susceptible again after having recovered from the infection. According to the continuously updated reports from the internet, it is known that the acquired immunity of the Covid-19 recovers can be reduced or destroyed by the environmental uncertainties, thus the loss of acquired immunity should really be considered to give a more realistic model. Motivated by this consideration and inspired by Ref.[2], we derive an improved SIDARTHE model by introducing the effect of acquired immunity loss, which can also enrich our model analysis. For the sake of convincing in dynamical analysis, we adopt the standard incidence rate and include the recruitment rate and the natural death into the model. This inclusion can be further validated by the long time prevalence of the COVID-19.

$$\begin{cases} \frac{dS}{dt} = \Lambda + \varpi H - (\alpha I + \beta D + \gamma A + \delta R)\frac{S}{N} - \chi S \\ \frac{dI}{dt} = (\alpha I + \beta D + \gamma A + \delta R)\frac{S}{N} - (\varepsilon + \zeta + \lambda + \chi)I \\ \frac{dD}{dt} = \varepsilon I - (\eta + \rho + \chi)D \\ \frac{dA}{dt} = \zeta I - (\theta + \mu + \kappa + \chi)A \\ \frac{dR}{dt} = \eta D + \theta A - (\nu + \xi + \chi)R \\ \frac{dT}{dt} = \mu A + \nu R - (\sigma + \tau + \chi)T \\ \frac{dH}{dt} = \lambda I + \rho D + \kappa A + \xi R + \sigma T - (\chi + \varpi)H \\ \frac{dE}{dt} = \tau T(t) \end{cases}$$

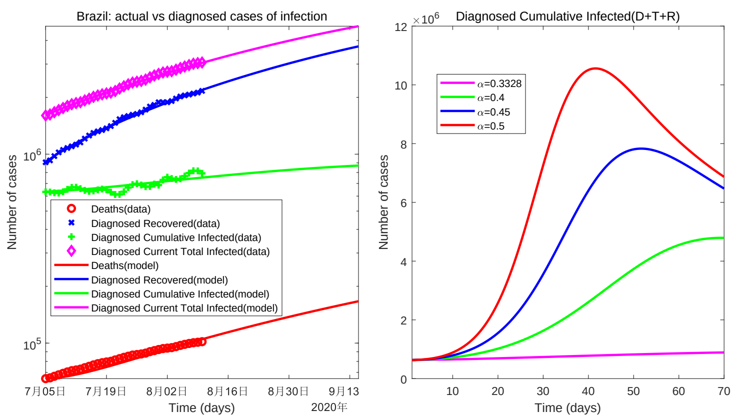

Figure 1: The model(left), epidemic evolution predicted in Brazil(middle) and sensitivity analysis with respect to α(right).

Results and discussion

After obtaining the basic reproduction number R_0 and analyzing the stability of the equilibrium point, we use the nonlinear data fitting method to minimize the least square error function to estimate the parameters and model predictions. Our findings can be summarized as follows: i) by enforcing strong social-distancing measures, that is, reducing the infection coefficients α, β, γ and δ plays a critical role in achieving the disease control; ii) the loss of immunity might result in another wave of infection. We believe that this research should be supportive in understanding continuous monitoring and intervention to control the COVID-19 outbreak in the world.

References

[1] Giordano, G., Blanchini, F., Bruno, R. et al. Modelling the COVID-19 epidemic and implementation of population-wide interventions in Italy. Nat Med 26, 855-860 (2020).
[2] López L, Rodó X. The end of social confinement and COVID-19 re-emergence risk.Nat Hum Behav. 2020;4(7):746-755.