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Short Report

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Forecasting Covid-19 epidemic in Isfahan using a dynamic modeling approach

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Abstract

The multidimensional destructions caused by Covid-19 have been compared to that of World War II. What makes the situation even more complicated is the ambiguity regarding the duration and the final size of the pandemic. It is critical especially for the governments, healthcare systems, and economic sectors to have an estimation of the future of this disaster. Using a dynamic model, we have here simulated the epidemic in Isfahan province, Iran for the episode of Feb 14th to April 11th and also have forecasted the remaining course with three scenarios which differ in terms of the stringency of social distancing. Results of this study indicate that in a “good scenario”, the epidemic could be overcome by following a strict lockdown for some weeks. Notably, even partial restrictions in the “feasible scenario” decline hospital admissions and mortality rates by one third compared to the “bad scenario” in which no limitation is imposed. Taken together, inattention to preventive strategies will result in a dramatic increase of the medical, social, and economical burden of the outbreak.

Key words: Covid-19; Mathematical models; Pandemics

Introduction

The recent outbreak of coronavirus disease 2019 (Covid-19), not only caused a huge burden on the health care systems, but also brought social and economic challenges to nearly all countries around the world. The high transmissibility rate as well as lack of efficient therapeutics has transformed the situation into a major challenge¹⁻³. Iran, the fifth country faced with the outbreak, announced the first cases on February 19, 2020. The pandemic quickly involved most of the country with the highest rates in Tehran, Qom and Isfahan provinces^{4,5}.

Since the 1918 influenza pandemics that caused 50 million deaths⁶, outbreaks with this scale have not been experienced. Hence, in spite of the occurrence of SARS, MERS, and Ebola epidemics, the risk of a world-wide disaster in the scale of Covid-19 was largely underestimated. It can describe why healthcare systems were underprepared even in developed countries. In addition, the future course of the disease is not yet clearly known in many affected countries and the estimations of the final size of the epidemic are not coherent. This makes policy makings and planning for the required resources very difficult for the governments⁷. In this regard, forecasting approaches are of special importance and can be inspiring.

Since the emergence of Covid-19, different mathematical modeling approaches have been employed to simulate the disease course⁸; artificial intelligence-based models⁹ are interesting. However, as they depend on lots of learning steps, their validity can be scrutinized in the lack of sufficient training datasets. Day-level forecasting based on time-series data is another approach¹⁰ which simply follows previous patterns and cannot predict trend changes. Agent-based modeling is also a wise approach for predicting disease course, which simulate the fellow of the individuals (agents) to calculate spread of the disease in the community¹¹. Nevertheless, such models rely on population-level parameters such as rates of movements and distancing as well as virus infectivity parameters which are not often exactly known. Ordinary differential equation (ODE)-based models have for a long time shown their efficacy to simulate the classical dynamism of epidemics¹². In such models, susceptible (S), infective (I), and recovered (R) fractions are assumed in a close population and the rate of changes in each portion is calculated with ODEs^{13,14}. Although based on simple assumptions, this approach can provide valuable insights on the course of the disease once a few epidemic parameters are known or estimated.

So far, various modified SIR models have been developed to predict the course of Covid-19; Anastassopoulou and colleagues, provided a primary estimation on ratio of fatality and recovery in the population of Wuhan by a discrete-time SIR model¹⁵. Moreover, a model was developed by Giordano and colleagues which predicted the effect of different lockdown strategies on the pandemics in Italy. They considered different sub-groups regarding stage and severity of the disease for infected individuals¹⁶. Similarly, using an SEIR (Susceptible-Exposed-Infectious-Removed) framework, Lin et al. predicted the effect of government policies and individual actions in the expansion of the epidemic in China¹⁷. Nevertheless, these modified SIR models acquire more complex data to be developed which due to presence of little information and lack of reliable

data regarding to this newly emerged disease, simple SIR models would perform much better than more complex ones, as Roda et. al proposed ¹⁸. In this study, we have developed an SIR-based model to predict Covid-19 course in Isfahan province in order to forecast hospitalization and mortality rates.

Material and Methods

SIR model

In the SIR models, population is considered to be closed and the sum of susceptible, infective or recovered fractions respectively denoted with $i(t)$, $s(t)$, and $r(t)$ is equal to 1 for all $t \geq 0$. The model is defined by the following set of ODEs:

$$\frac{ds}{dt} = -\lambda si \quad (1)$$

$$\frac{di}{dt} = \lambda si - \gamma i \quad (2)$$

$$\frac{dr}{dt} = \gamma i \quad (3)$$

Where, λ is the infection rate and γ is the recovery rate. R_0 known as basic reproduction number is defined as:

$$R_0 = \frac{\lambda}{\gamma} \quad (4)$$

R_0 is an essential determinant of outbreaks and can be interpreted as the expected number of new cases directly caused by an infectious individual before recovery.

All simulations were performed using MATLAB R2017a ¹⁹.

Epidemiological data

The data used in this study is provided by the medical care monitoring center (MCMC) of Isfahan University of Medical Sciences, Isfahan, Iran. This data stands for the daily hospitalized cases and deaths from all cities of Isfahan province except Kashan, Aran and Bidgol which are in the zone of Kashan University of Medical Sciences. The population in the studied region is approximately 4'632'000. Considering the low negative predictive value of PCR test for the diagnosis of Covid-19 ²⁰, all patients admitted to hospitals with clinical suspicion of the disease were considered as infected cases. This can describe potential discrepancies between the actual cases assumed in this study and other reports which rely on molecular diagnosis of the infection.

Results

In the SIR model, $r(t) + i(t)$ determines all the individuals who are no longer susceptible. The term can be interpreted as the accumulated number of new cases in each time-point which due to the course of disease could be recovered, died or still infectious. According to recent studies, 30% of infected individuals are asymptomatic ²¹. From all remaining infective cases, 70% show mild to moderate symptoms and are treated in out-patient settings while, 30% have more severe manifestations and should be admitted to hospitals for a while during the infection. Hence, the cumulative new hospital-admitted cases can be estimated from equation (5):

$$\text{Cumulative hospitalized patients} = 0.21 (r(t) + i(t)) \quad (5)$$

In addition, the number of cumulative deaths is assumed as:

$$\text{Cumulative death} = K \times (r(t) + i(t)) \quad (6)$$

Although a mortality rate of 2-3% is reported for Covid-19 patients ^{22,23}, the actual rate depends on a variety of parameters including the average age of the population and the healthcare system. In this regard, the parameter K is determined for each population individually based on the reported mortality rates.

In order to estimate the R_0 value for the Covid-19 epidemic, the model was first fitted with the cumulative new cases data reported up to April 10th, 2020 from Wuhan and Italy and then it was fine-tuned based on Isfahan statistics. An R_0 of 1.0078 could best describe the data of Italy. Also, the curves of Wuhan could be appropriately simulated when R_0 was assumed 1.0146 (Fig 1). Notably, the number of new hospital-admitted cases shows a decline in days 40-50 in Italy which could be attributed to the strict social isolation policies imposed by the government (Fig 1a). To fit the model on the mortality data, parameter K (Eq. (6)) was set at 0.025 for Italy. Notably, when the same value was considered for Wuhan, the simulation curve was far higher than the reported official data (Fig 1b). In agreement with this observation, Chinese authorities have recently declared the inaccuracy of initial reports of deaths in Wuhan and boosted the number by 50% ²⁴.

The simulations for Wuhan and Italy allowed to start modeling the epidemic in Isfahan with a rough estimation of R_0 magnitude. Although in classical SIR models, each outbreak is described with a unique R_0 ^{25,26}, we decided to use a set of R_0 values for different time intervals to account for the variations of the community behavior and inconsistency of social distancing regulations. At the time of model construction, actual epidemiological data were available for the episode of Feb 14th to April 11th. The model was best fit to the actual data when four different R_0 values were considered. Since change in the social performance is reflected in the hospital admission rates with a time delay of about 2 weeks ²⁷, the four R_0 values were corroborated with community behavior variations as represented by city traffic reports (data not shown).

To forecast the epidemic in this province, three scenarios based on the strictness of social distancing were assumed and for each case, different R_0 values were considered (table 1). From Feb 14th to April 11th, the highest value of R_0 was 1.0165 (R_{01}) which is attributed to the beginning of the epidemic when people were not aware of the outbreak and so no restriction was undertaken. In the “bad scenario”, R_0 again reaches the same value after a transitional step. In addition, during the mentioned period, the smallest value of R_0 was 1.0040 (R_{03}). Hence, considering practical issues, it is assumed that R_0 may again reach to a value as small as 1.0050 in the “good scenario”. An intermediate value of 1.0095 is considered for the “feasible scenario”.

Table 1: R_0 values used in the SIR model

Simulating actual data				Forecasting	
R_{01}	R_{02}	R_{03}	R_{04}		
02/14- 02/28	02/29- 03/14	03/15- 03/28	03/29- 04/12		
				Scenarios	R_{05} 04/13- 04/27
				Good	1.0055
				Feasible	1.0090
				Bad	1.0110
1.0165	1.0060	1.0040	1.0085		R_{06} $\geq 04/28$ 1.0050
					1.0095
					1.0165

In the good scenario achieved by strict social distancing, the SIR model predicts that by the end of the epidemic, about 13'000 cases will be cumulatively hospitalized and the total number of deaths will reach 800 cases. The curve of cumulative cases will approach a plateau in May 4 and by June 10, only 0-2 new cases will be daily admitted to hospitals (Fig 2a).

Feasible scenario can be attributed to closing schools, universities, and cultural centers, limiting social gatherings and businesses that are not critical. In this scenario, the model predicts that total hospitalized cases and deaths will reach about 15'000 and 920, respectively. Also, the curve of cumulative cases will approach a plateau in May 24 and by the July 18, only 0-2 new cases will be daily admitted to hospitals (Fig 2b).

In the bad scenario a situation is assumed in which the society is back to the routine life style. In this scenario, 22'000 cases will be totally admitted to the hospitals and the number of victims will be more than 1'300. Although, a second peak is unlikely, the epidemic will descend very slowly and will last up to mid-August (Fig 2c). The results of three scenarios are summarized in Table 2.

Table 2- Predicted outcomes of the three proposed Scenarios

Scenarios	Final epidemic size ¹	Total deaths	Total hospitalizations	Cessation date ²
Good	1.4%	803	12969	Jun 10, 2020
Feasible	1.5%	922	14902	July 18, 2020
Bad	2%	1373	22175	Aug 15, 2020

1- The proportion of the community that becomes affected by the end of the epidemic

2- Daily hospitalized new cases ≤ 2

To predict number of deaths using equation (6), a value of 0.013 for K could provide the best fit of simulation and actual curves, especially in the early days. However, after 45 days, actual number of deaths fall below model predictions which can be described by an improved performance of the health care system.

Discussion

In this study an SIR-based model is proposed to predict the course of Covid-19 epidemic in Isfahan. The scenarios proposed in this study illustrate three fates which differ in terms of number of infections, deaths, the duration of the epidemic, and the proportion of the community who become affected. Considering the economical and psychosocial consequences, one may scrutinize the rationality of a very restrict lockdown. However, this study shows that even a partial restriction which decreases R_0 from 1.0165 (that happens when no limitation is implemented) to 1.0095 will have a dramatic impact in declining hospital admission and mortality rates by one third. We believe this scenario is “feasible” as even a smaller R_0 value of 1.0040 has been previously experienced. This scenario is probably equivalent to limiting out-door activities to critical tasks and suspending unessential businesses.

Predictive models developed by other investigators also propose mitigation strategies to shorten disease course and reduce the number of infections; a model of the epidemic in Singaporean population predicts that a combined strategy including quarantine of the infected individuals and their family members, school closure, as well as workplace distancing would markedly reduce the number of infections²⁸. In agreement with our findings, a study by Ferguson et al. shows that strict suppression strategies only work in short term and would reverse upon opening the lock down

whereas intermittent social distancing along with school closure would reduce peak infected individuals with less economic crisis ².

Taken together, we have improved classical SIR models through considering a set of R_0 values instead of a fixed one to account for real variations that may happen in the response of the community to an unpredicted outbreak. The proposed model demonstrates that although a second peak is unlikely, the burden of the disease can be considerably reduced by a balanced and feasible plan for social distancing.

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Competing Interests: The authors declare no competing interest.

Authors Contribution: J.G, Y.G, and S.H.J conceptualized the main idea. S.H.J, Y.G, S.M, and A.R gathered and interpreted the actual data. J.G, N.N, N.B and Z.H performed simulations. Y.G and S.M drafted the manuscript. J.G, N.N, A.R, and S.H.J revised the manuscript. All authors made a substantial intellectual contribution to the work, and approved the submitted version for publication.

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Figure Legends:

Figure 1- Modeling Covid-19 epidemic in Wuhan and Italy. To provide a rough estimation of the epidemic dynamics, the model was first generated with the reported data of Wuhan and Italy. a, b) Epidemic final size. c, d) Cumulative hospitalized cases. e, f) Cumulative deaths.

Figure 2- Modeling Covid-19 epidemic in Isfahan province. To forecast the epidemic, Good (a), Feasible (b) and Bad (c) Scenarios are assumed.

Figures

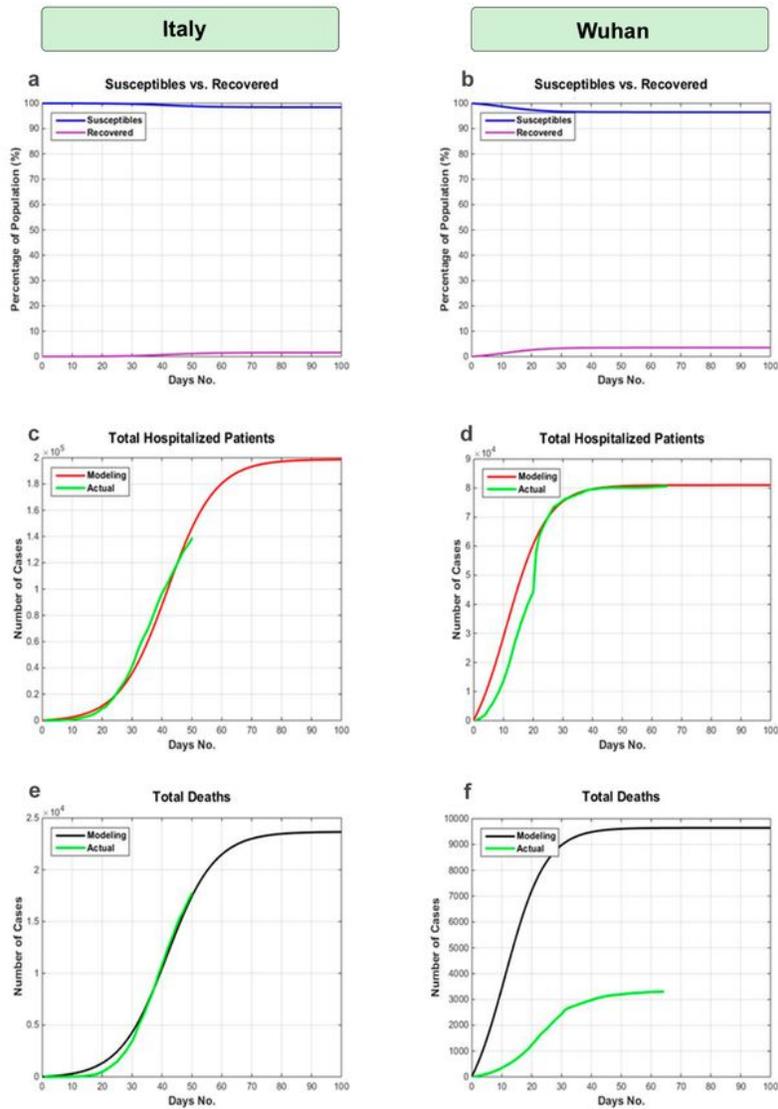


Figure 1

Modeling Covid-19 epidemic in Wuhan and Italy. To provide a rough estimation of the epidemic dynamics, the model was first generated with the reported data of Wuhan and Italy. a, b) Epidemic final size. c, d) Cumulative hospitalized cases. e, f) Cumulative deaths.

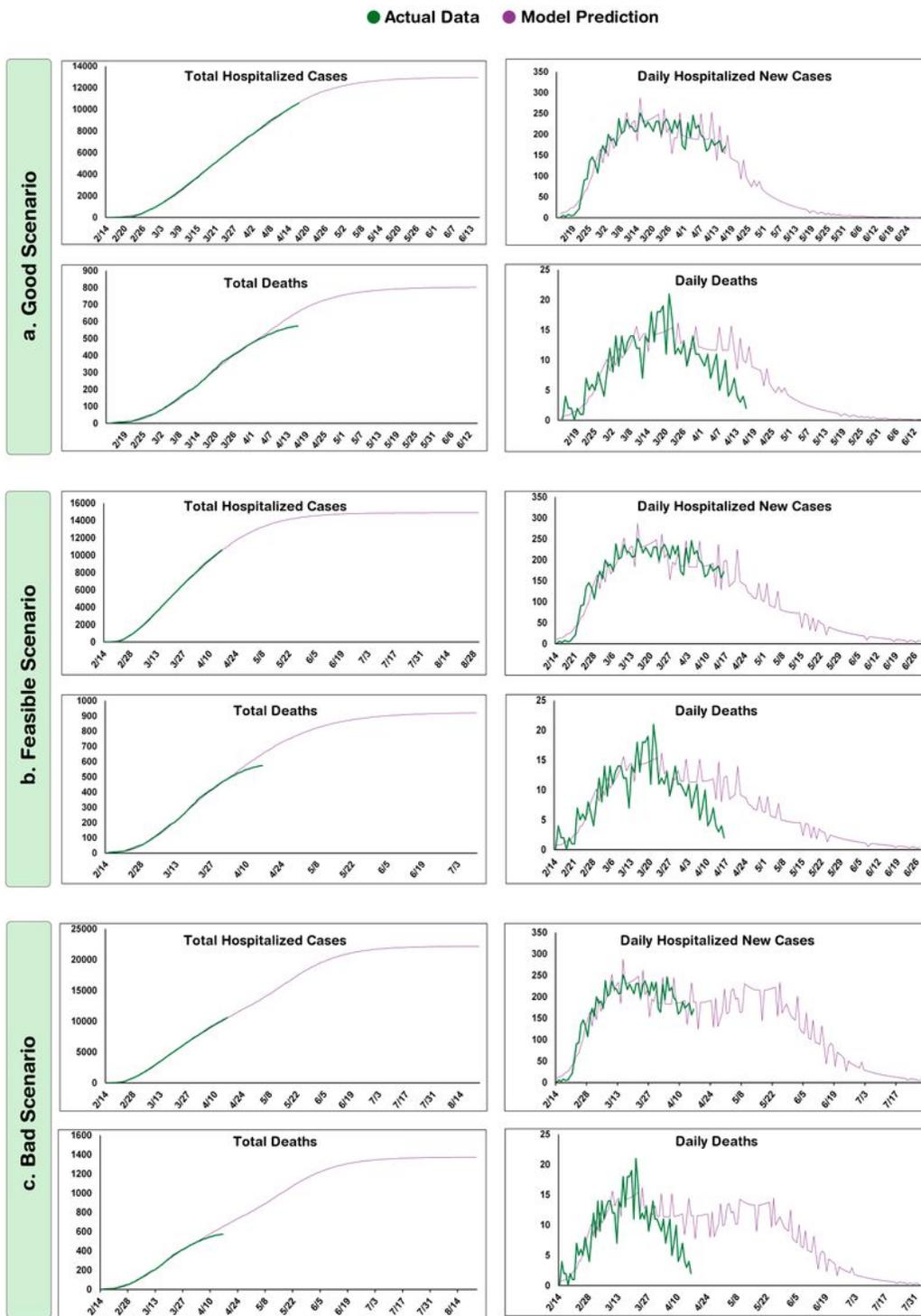


Figure 2

Modeling Covid-19 epidemic in Isfahan province. To forecast the epidemic, Good (a), Feasible (b) and Bad (c) Scenarios are assumed.