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Vertical social distancing policy is ineffective to contain the COVID-19 pandemic

A política de distanciamento social vertical é ineficaz para conter a pandemia da COVID-19

La política de aislamiento social vertical es ineficaz para contener la pandemia de COVID-19

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Abstract

Considering numerical simulations, this study shows that the so-called vertical social distancing health policy is ineffective to contain the COVID-19 pandemic. We present the SEIR-Net model, for a network of social group interactions, as a development of the classic mathematical model of SEIR epidemics (Susceptible-Exposed-Infected (symptomatic and asymptomatic)-Removed). In the SEIR-Net model, we can simulate social contacts between groups divided by age groups and analyze different strategies of social distancing. In the vertical distancing policy, only older people are distanced, whereas in the horizontal distancing policy all age groups adhere to social distancing. These two scenarios are compared to a control scenario in which no intervention is made to distance people. The vertical distancing scenario is almost as bad as the control, both in terms of people infected and in the acceleration of cases. On the other hand, horizontal distancing, if applied with the same intensity in all age groups, significantly reduces the total infected people "flattening the disease growth curve". Our analysis considers the city of Belo Horizonte, Minas Gerais State, Brazil, but similar conclusions apply to other cities as well. Code implementation of the model in R-language is provided in the supplementary material.

COVID-19; Social Distance; Epidemiologic Models

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Introduction

In Brazil, there is a widespread belief that the so-called vertical social distancing health policy, just restricting social contact with older people – and higher risk individuals –, would be enough to contain the propagation of the SARS-CoV-2 coronavirus disease (COVID-19). This idea assumes that people under the age of 60 would suffer only mild symptoms and could leave their houses to work and study during the epidemic. However, we have observed a high number of hospitalizations, with severe cases and deaths also affecting people under 60 years old and without underlying diseases. Besides, social distancing is not a strict rule, and older people tend to make social contacts during the period, increasing the possibility of infection. Through this study, we shall use the terms "social distance" and "social isolation" interchangeably to indicate a reduction in the intensity of social contact.

Social distance measures in the COVID-19 pandemic are already proving its effectiveness, reducing the number of infected people [1,2,3,4,5,6,7]. Why is it important? Mainly because we want the peak of the epidemic to be minimized, to avoid overloading the health system with many people requiring intensive care simultaneously because of COVID-19 and its symptoms. This goal of the public health services is popularly known as "flattening the curve" of cases and hospitalizations. If there are not enough hospital beds to serve everyone, many people may die from lack of care. Postponing the peak of cases would be potentially beneficial so health managers are better prepared, and so researchers can find more effective treatments. Therefore, if social distancing can reduce the peak of infected people, at the same time postponing its occurrence, many lives can be saved.

We will analyze these problems with a mathematical technique for simulating the evolution of epidemics, the SEIR-Net model, obtained from a modification of the traditional SEIR model (Susceptible-Exposed-Infected-Removed). In the SEIR model, people susceptible to infection randomly come into contact with the SARS-CoV-2 virus becoming exposed. After the incubation period, they are infected and can pass this virus at random to other susceptible people. Infected people can be asymptomatic (have few or no symptoms) or symptomatic (develop typical symptoms of COVID-19 infection). Infected people become, over time, removed (a technical term to say that they cannot infect other people and may survive or die). In this model, we use an estimate of unreported cases, based on the reported (confirmed) cases. This extrapolation/estimation happens because it is not possible to test the entire population. In Brazil, the estimates show at least 20 times more unreported than reported cases, and it was based on model fitting using a mathematical SEIR model for the disease spread in Minas Gerais State [8]. Still, this number now is probably much higher, mainly due to the scarcity of available test kits. Our model assumes that the contact among persons follow a uniformly random pattern of interaction, and apart from the age groups, there is no spatial (geographic) restriction to social contact – which is embedded into the B transmission parameter determined empirically from the observed data at the beginning of the epidemic.

Some parameters are important in this simulation, such as the average incubation time (Z), the average infectious period (D) (for how many days the infected individual can infect others), and the fraction of asymptomatic infected individuals still capable of infecting others (although with less intensity). An important parameter, which does not depend only on the virus, is the transmission rate (B); it depends on the country's health system and the population's living conditions. If B is high, it means that the virus tends to spread more quickly. All COVID-19 parameters used in this study were obtained from the article [9] and adapted to the observed case data from Belo Horizonte, Minas Gerais State [8]. Publicly available population data was used (Departamento de Informática do SUS. População residente – estudo de estimativas populacionais por município, idade e sexo 2000-2015 – Brasil. http://tabnet.datasus.gov.br/cgi/tabcgi.exe?novapop/cnv/popbr.def, accessed on 03/Apr/2020).

In the next section, we will build our new model SEIR-Net with social distancing and network interaction. In the following section, we will present several scenarios simulating different conditions of vertical and horizontal social distancing in Belo Horizonte and study their impact on reducing simultaneously infected people. Code implementation of the model in R-language is provided in the Supplementary Material (http://cadernos.ensp.fiocruz.br/site/public_site/arquivo/suppl-e00084420_6775.pdf).

The SEIR-Net model

The model proposed in this study is a development of the model used in Takahashi [8], and generalizes the SEIR is model proposed in Duczmal et al. [10]. The recent model by Prem et al. [3] also uses the SEIR model with a partitioning of the population into groups and considers their interaction.

The SEIR-Net model divides the population between n social distancing groups and uses the *F Contact Fraction Matrix*, given by:

$$F = \begin{pmatrix} F_{11} & \cdots & F_{1n} \\ \vdots & \ddots & \vdots \\ F_{n1} & \cdots & F_{nn} \end{pmatrix}$$

Where the entry F_{ij} indicates the contact intensity of virus transmission from an individual in the group i to an individual in the group j, where $0 \leq F_{ij} \leq 1$. If $F_{ij} = 1$, then the contact is not restricted, and if $F_{ij} = 0$ no individual in the group *i* can transmit the virus to any individual in the group *j*. This system connects the n groups. In our study, we will use groups formed by age groups in the city of Belo Horizonte. In future work, we will extend this idea to groups divided by income level, place of residence or work, occupation, etc.

How will the COVID-19 epidemic evolve in this case? In the next section we will analyze scenarios with different structures for the F matrix.

Case studies

In the SEIR-Net model, we can simulate social contact between groups divided by age and analyze different strategies of social distancing.

The population of Belo Horizonte, with approximately 2.5 million inhabitants, has the following age distribution interpolated for 2015 (Departamento de Informática do SUS. População residente – estudo de estimativas populacionais por município, idade e sexo 2000-2015 – Brasil. http://tabnet.datasus.gov.br/cgi/tabcgi.exe?novapop/cnv/popbr.def, accessed on 03/Apr/2020): 0-9 years old: 11.7%; 10-24 years old: 21.8%; 25-59 years old: 52.3%; 60+ years old: 14.2%.

Initially, we present a control scenario without distancing intervention. In this case, all elements *Fij* of the F matrix are equal to 1.

In vertical distancing, only people aged 60+ years old are socially distanced. The F matrix is given by:

$$F = \begin{bmatrix} 1 & 1 & 1 & c \\ 1 & 1 & 1 & c \\ 1 & 1 & 1 & c \\ c & c & c & c \end{bmatrix}$$

Where $c = 1/k$ means that contact between individuals aged 60+ years old have a k-fold reduced social contact with individuals of all age groups and *vice versa*.

Finally, in horizontal distancing, individuals of all age groups adhere to distancing. The F matrix becomes:

$$F = \begin{bmatrix} c & c & c & c \\ c & c & c & c \\ c & c & c & c \\ c & c & c & c \end{bmatrix}$$

Where the value of c depends on the social contact reduction factor. A value of $c = 1/15$ corresponds to the estimated social contact reduction factor for New York city, USA, during the end of March, with a 15-fold social contact reduction, meaning that social contact was reduced by $1 - 1/15 = 93\%$ [2]. When $c = 1$, we go back to the control scenario, with 0% of social contact reduction. As we will see, a value of $c = 0.55$ (1.8 fold, i.e., 45% reduction of social contact) for the above matrix is consistent with the observed data in Belo Horizonte.

The results of the simulations using the SEIR-Net model are presented below.

The four dashed curves measure the cumulative number of individuals infected over time for each age group, according to the legend. The solid curve indicates the number of individuals from all age groups currently infected. The thin dotted horizontal lines indicate the persons for each age group, thus showing the ceiling for the accumulated possible infected persons in each group.

The numbers in parentheses indicate the approximate percentage of each age group within the population.

In the control scenario (without distancing) of Figure 1, about 500,000 simultaneously infected people is the maximum reached approximately 55 days after the beginning of the epidemic. The number of infected people is extremely high for all age groups. Within the age group of 60+ years old, we would have more than 350,000 infected people accumulated over the period.

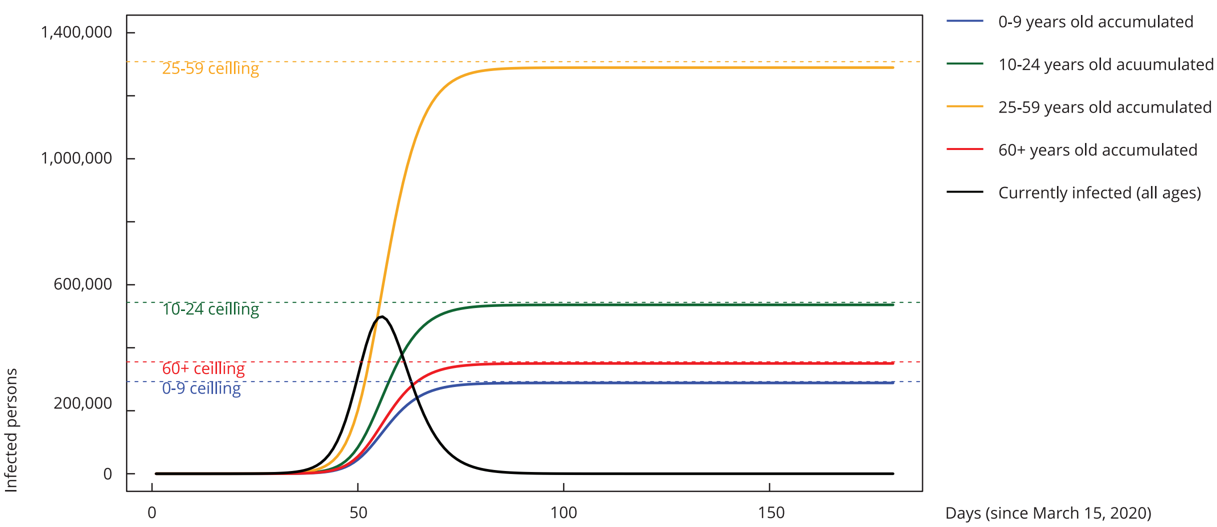
In the scenario of vertical distancing, with a 4-fold (75%) reduction of social contact exclusively for the 60+ years old age group (Figure 2), about 400,000 simultaneously infected people is the maximum reached approximately 65 days after the beginning of the epidemic. The number of infected people is extremely high for all age groups. In the 60+ years old group, we would have more than 200,000 infected people accumulated. In other age groups, virtually everyone would be infected.

Horizontal distancing with the same 4-fold (75%) reduction of social contact, for all age groups, is shown in Figure 3. The epidemic does not reach significant dimensions in the first 180 days of simulation. As can be seen in Figure 4, the number of simultaneously infected people only becomes significant about 18 months later, with a relatively small number of simultaneously infected people (less than 10,000).

By the end of March, the estimate was that social contact would decrease between 30% and 50% (corresponding to contact intensity between 0.50 and 0.70) in Belo Horizonte [11]. The intensity of c = 0.55, corresponding to (1/0.55) = 1.8-fold (i.e. 45%) reduction in social contact, results in the graph of Figure 5. This graph shows that the 1.8-fold reduction is not sufficient to deter the epidemic outbreak, as could be observed by the accumulated case's curves reaching more than 85% of the ceiling limit of infected persons for all groups. The peak of simultaneous infections (more than 200,000) is reached after about 105 days.

Figure 1

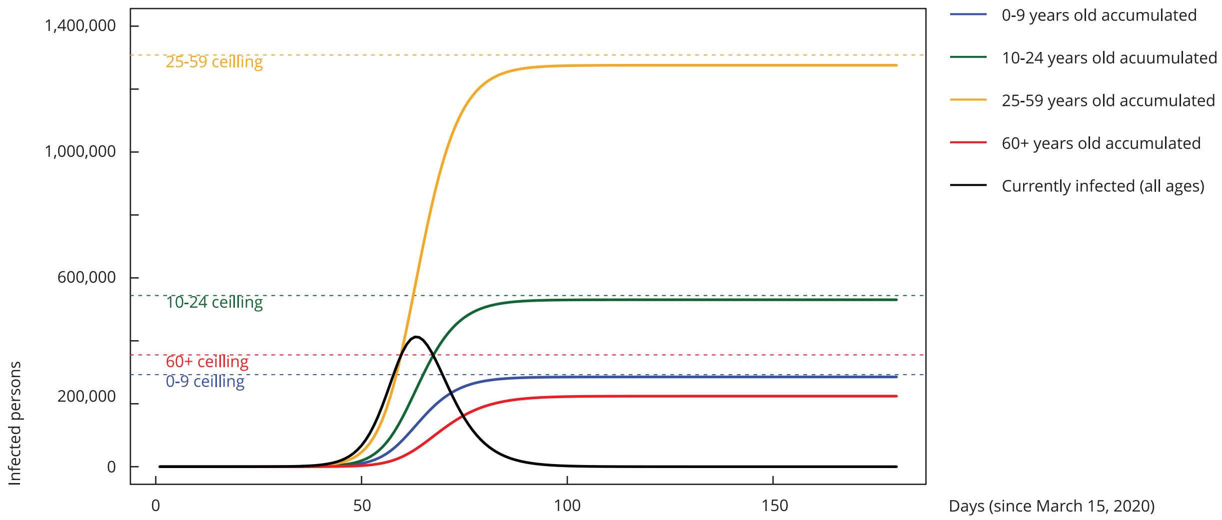
Control scenario without any social distancing, presented for comparison purposes.



Note: age groups: 0-9 years old (12%), 10-24 years old (22%); 25-59 years old (52%); 60+ years old (14%) with no interventions.

Figure 2

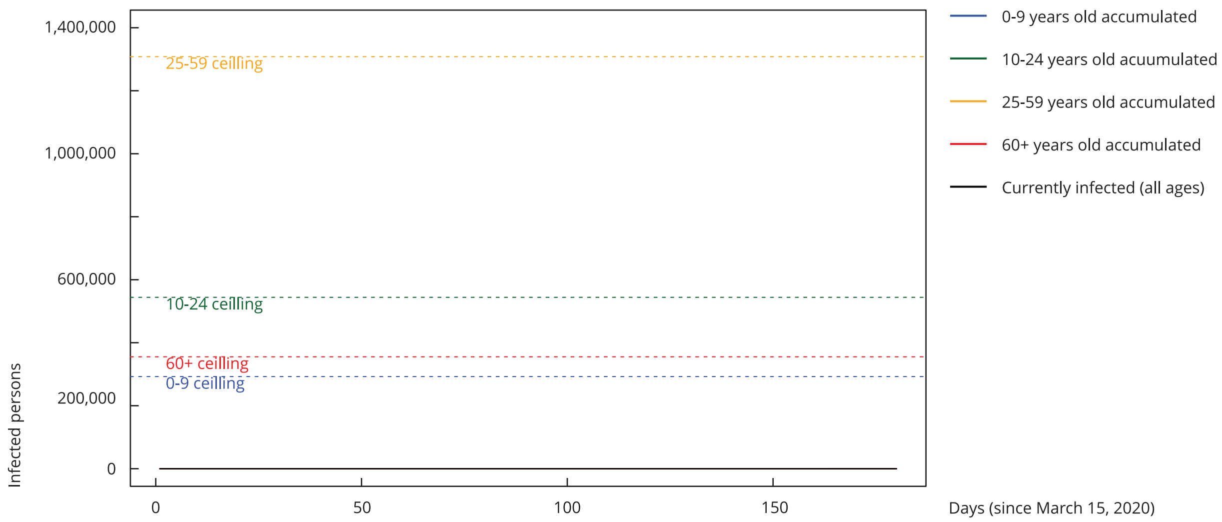
Vertical distancing, only with the 60+ years old age group socially distanced (4-fold, i.e. 75% reduction).



Notes: age groups: 0-9 years old (12%), 10-24 years old (22%); 25-59 years old (52%); 60+ years old (14%) with vertical isolation (4-fold (75%) reduction only for 60+ years old age group). This scenario is almost as unfavorable as the scenario in which there is no distancing at all.

Figure 3

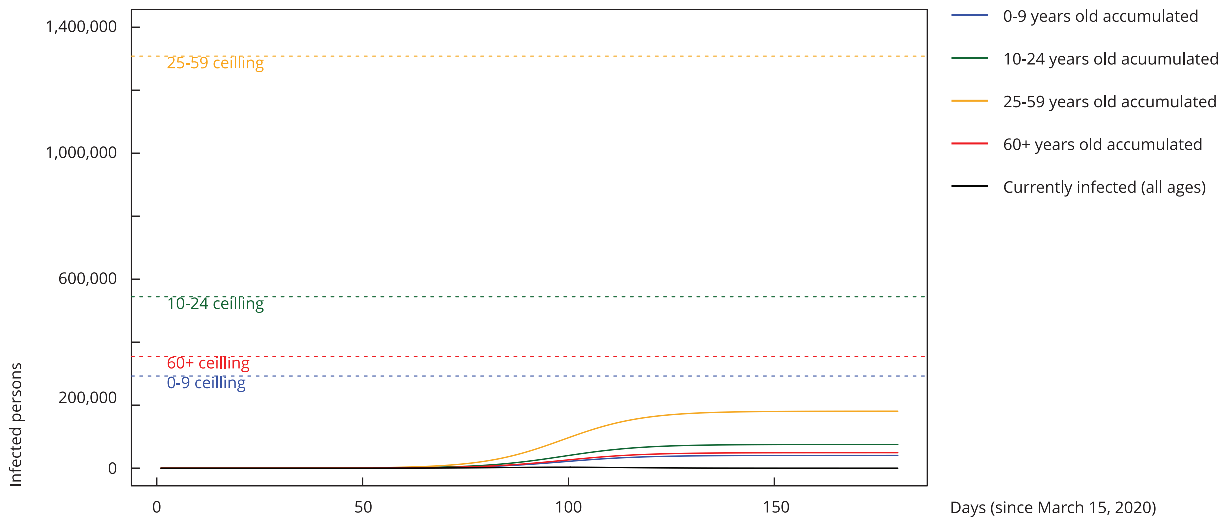
Horizontal distancing, with a 4-fold social contact intensity factor (75% reduction) for all age groups.



Note: age groups: 0-9 years old (12%), 10-24 years old (22%); 25-59 years old (52%); 60+ years old (14%) with horizontal isolation (4-fold (75%) reduction for all age groups). The epidemic does not reach significant levels in the first 180 days of simulation.

Figure 4

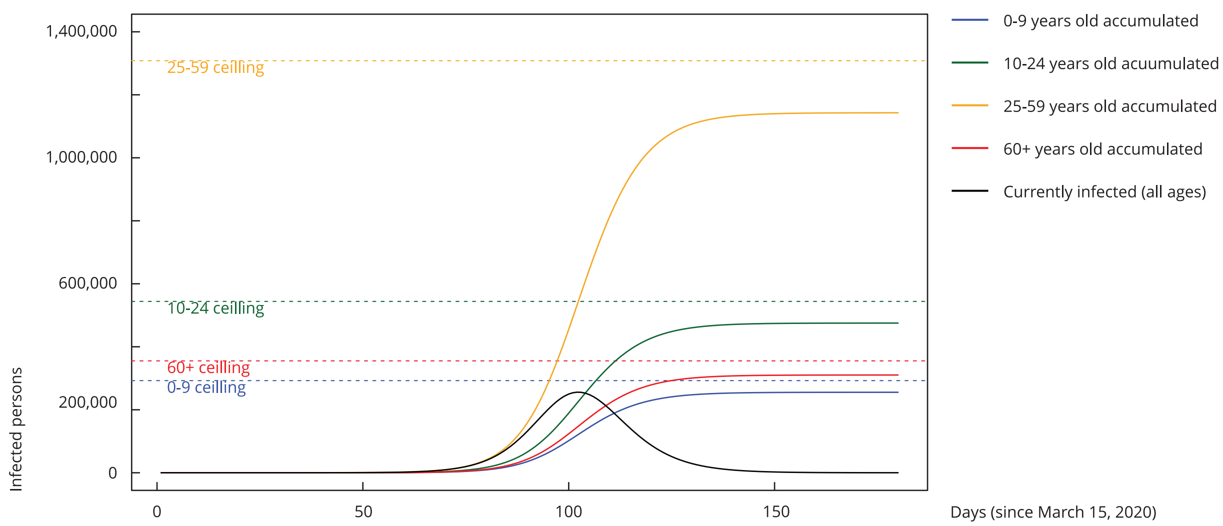
Same as the previous scenario, here displayed for five years, for the horizontal distancing, with a 4-fold social contact intensity factor (75% reduction) for all age groups.



Note: age groups: 0-9 years old (12%), 10-24 years old (22%); 25-59 years old (52%); 60+ years old (14%) with horizontal isolation (4-fold (75%) reduction for all age groups). The epidemic only manifests itself in a reduced way, about 18 months later.

Figure 5

Scenario using a 1.8-fold (45%) social contact reduction.



Note: age groups: 0-9 years old (12%), 10-24 years old (22%); 25-59 years old (52%); 60+ years old (14%) with horizontal isolation (1.8-fold (45%) reduction for all age groups). This is not enough to deter the epidemic.

Conclusions

Vertical distancing is only marginally better than no social distancing at all – and much worse than the horizontal distancing scenario – with an equivalent level of reduction in social contact.

Vertical distancing with a 4-fold (75%) reduction in social contact only for the 60+ years old age group could not prevent a large number of older people infected (more than 200,000), with 350,000 individuals simultaneously infected. This scenario would also overload the healthcare system in Belo Horizonte.

Horizontal distancing, with a similar 4-fold (75%) reduction for all age groups, should slow the surge of cases, postponing the peak for about two years. That should relieve the hospital network, reducing the number of fatal victims, allowing future interventions (vaccination, new treatments, etc.).

However, this 4-fold reduction is far from being adopted by the general population. Mobility data for Belo Horizonte shows only a 1.8-fold (45%) reduction in social contact during the last two weeks, which is clearly not sufficient to deter the epidemic outbreak. An urgent effort is recommended to improve reduction of social contact through a strong horizontal distancing health policy for several months.

Contributors

L. H. Duczmal and C. R. L. Alves participated in the conception and design, acquisition, analysis and interpretation of data, draft and review of the article and approval of the final version. A. C. L. Almeida, D. B. Duczmal, F. C. O. Magalhães, M. S. Lima, I. R. Silva and R. H. C. Takahashi contributed in the conception and design, acquisition, analysis and interpretation of data and approval the final version.

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Resumo

O artigo demonstra através de simulações numéricas que a política do chamado distanciamento social vertical é ineficaz para conter a pandemia da COVID-19. Os autores apresentam o modelo SEIR-Net para uma rede de interações entre grupos sociais, enquanto desdobramento do modelo matemático clássico para epidemias, chamado SEIR (Suscetíveis-Expostos-Infectados (sintomáticos e assintomáticos)-Removidos). No modelo SEIR-Net, pode-se simular contatos sociais entre grupos, divididos por faixas etárias, e analisar diferentes estratégias de distanciamento social. Na política de distanciamento vertical, apenas os idosos ficam distanciados, ao contrário da política de distanciamento horizontal, em que todas as faixas etárias aderem ao distanciamento. O artigo compara esses dois cenários a um cenário controle, sem nenhuma intervenção para distanciar as pessoas umas das outras. O cenário do distanciamento vertical é quase tão ruim quanto aquele sem nenhum distanciamento, em termos tanto do número de infectados quanto da aceleração do número de casos. Por outro lado, o distanciamento horizontal, desde que aplicado com a mesma intensidade a todos os grupos etários, reduz significativamente o número total de infectados e "achata a curva de crescimento da doença". Nossa análise foi feita no Município de Belo Horizonte, Minas Gerais, Brasil, mas conclusões semelhantes se aplicam igualmente a outras cidades. O material suplementar do artigo fornece detalhes sobre a implementação do código do modelo na linguagem R.

COVID-19; Distância Social; Modelos Epidemiológicos

Resumen

Demostramos mediante simulaciones numéricas que la denominada política de salud de aislamiento social vertical es ineficaz para contener la pandemia de COVID-19. Presentamos el modelo SEIR-Net para interacciones de grupo en una red social, como una evolución del clásico modelo matemático SEIR epidemics (Susceptibles-Expuestos-Infectados (sintomáticos y asintomáticos)-Removidos). En el modelo SEIR-Net, podemos simular contactos sociales entre grupos divididos por grupos de edad y analizar diferentes estrategias de distanciamiento social. En la política de aislamiento vertical, solamente se aísla a los ancianos, frente a la política de aislamiento horizontal, donde todos los grupos de edad se adhieren al aislamiento social. Estos dos escenarios se compararon a un escenario de control, en el que no se realiza ninguna intervención para aislar a la gente. El escenario de aislamiento vertical es casi tan malo, como el escenario donde no se aplica ningún tipo de aislamiento, tanto en términos del número de infectados, como en la aceleración del número de casos. Por otro lado, el aislamiento horizontal, si se aplica con la misma intensidad en todos los grupos de edad, reduce significativamente el número total de infectados y "aplana la curva de crecimiento de la enfermedad". Nuestro análisis se realiza en la municipalidad de Belo Horizonte, Minas Gerais, Brasil, pero conclusiones similares se pueden aplicar también a otras ciudades. En el material complementario se facilita la implementación del código del modelo en R-language.

COVID-19; Distancia Social; Modelos Epidemiológicos

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