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PREDICTIVE MODEL FOR COVID-19 INCIDENCE IN A MEDIUM-SIZED MUNICIPALITY IN BRAZIL (PONTA GROSSA, PARANÁ)

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ABSTRACT

Objective: to produce a predictive model for the incidence of COVID-19 cases, severity and deaths in Ponta Grossa, state of Paraná.
Methods: this is an ecological study with data from confirmed cases of COVID-19 reported between March 21, 2020 and May 3, 2020 in Ponta Grossa and proportion of severity, hospitalization and lethality in the literature. A susceptible-infected-recovered (SIR) epidemic model was developed, and reproduction rate (R_0), duration of epidemic, peak period, number of cases, hospitalized patients and deaths were estimated. Deaths were calculated by age group and in three scenarios: at day 24, at day 34, and at day 44 of the epidemic.
Results: in the three scenarios assessed in this study, the variation in the number of cases was explained by an exponential curve (r^2=0.74, 0.79 and 0.89, respectively, $p<0.0001$ in all scenarios). The SIR model estimated that, in the best scenario, the peak period will be around 120 days after the first case (between July 11, 2020 and July 25, 2020), estimated R_0 will be 1.07 and will infect 0.23% of the population. In the worst scenario, peak period will involve 4,375 (95% CI; 4156-4594) cases and 825 (95% CI; 700-950) cases in the best scenario. Most cases and hospital admissions will involve patients aged 20 to 39 years, the number of deaths will be higher among the elderly and more pronounced among patients aged ≥80 years.
Conclusion: this is the first study that provides COVID-19 projections for a municipality that is not a large capital. It shows a peak period at a later moment; therefore, the municipality will have more time to prepare and adopt protective measures to reduce the number of simultaneous cases.

DESCRIPTORS: Estimate. Epidemics. Basic reproduction number. Coronavirus. SARS-CoV-2. Mortality. Hospitalization.

HOW CITED: Martins CM, Gomes RZ, Muller EV, Borges PKO, Coradassi CE, Montiel EMS. Predictive model for COVID-19 incidence in a medium-sized municipality in Brazil (Ponta Grossa, Paraná). Texto Contexto Enferm [Internet]. 2020 [cited YEAR MONTH DAY]; 29:e20200154. Available from: https://doi.org/10.1590/1980-265X-TCE-2020-0154

MODELO PREDITIVO DA OCORRÊNCIA DE COVID-19 EM MUNICÍPIO DE MÉDIO PORTE NO BRASIL (PONTA GROSSA-PARANÁ)

RESUMO

Objetivo: obter um modelo preditivo da ocorrência de casos, gravidade e óbitos por COVID-19 em Ponta Grossa-Paraná.
Métodos: estudo ecológico com dados de casos confirmados de COVID-19 notificados de 21/03/2020 a 03/05/2020 em Ponta Grossa e proporção de gravidade, hospitalização e letalidade da literatura. Um modelo epidemiológico suscetível-infectado-recuperado (SIR) foi construído e estimadas taxa de reprodução (R_0), duração da epidemia, data do pico, número de casos, hospitalizações e óbitos. Estas últimas por faixa etária e em três cenários: aos 24 dias, aos 34 dias e aos 44 dias de epidemia.
Resultados: nos três cenários avaliados, a variação no número de casos foi explicada por uma curva exponencial (r^2=0,74,0,79 e 0,89, respectivamente e p<0,0001 em todos). O modelo SIR estimou que, no melhor cenário, o pico ocorrerá em torno de 120 dias após o primeiro caso (entre 11/07/2020 e 25/07/2020), o R_0 estimado será 1,07 e chegará a 0,23% dos habitantes infectados. No pior cenário, o pico estimado será de 4375 (IC 95% 4156-4594) casos e 825 (IC 95% 700-950) no melhor cenário. O maior número estimado de casos e hospitalizações será na faixa entre 20 e 39 anos, o número de óbitos será maior entre idosos e mais acentuado entre ≥ 80 anos.
Conclusão: este é o primeiro estudo com projeções para a COVID-19 em um município fora das grandes capitais e mostrou que o pico será tardio, portanto, o município terá mais tempo de preparo e que medidas protetivas podem reduzir o número simultâneo de casos.

DESCRITORES: Previsão. Epidemias. Número reprodutivo basal. Coronavirus. SARS-CoV-2. Letalidade. Hospitalização.

MODELO PREDICTIVO DE LA OCURRENCIA DE COVID-19 EN UN MUNICIPIO DE TAMAÑO MEDIO EN BRASIL (PONTA GROSSA-PARANÁ)

RESUMEN

Objetivo: obtener un modelo predictivo para la ocurrencia de casos, severidad y muertes por COVID-19 en Ponta Grossa-Paraná.
Métodos: estudio ecológico con datos de casos confirmados de COVID-19 notificados del 21/03/2020 al 3/3/2020 en Ponta Grossa y proporción de severidad, hospitalización y letalidad en la literatura. Se construyó un modelo epidemiológico (SIR) infectado-recuperado susceptible y tasa de reproducción estimada (R0), duración de la epidemia, fecha pico, número de casos, hospitalizaciones y muertes. Este último por grupo de edad y en tres escenarios: a los 24 días, a los 34 días y a los 44 días de epidemia.
Resultados: en los tres escenarios evaluados, la variación en el número de casos se explicó por una curva exponencial (r2 = 0.74, 0.79 y 0.89, respectivamente y p <0.0001 en total). El modelo SIR estimó que, en el mejor escenario, el pico ocurrirá alrededor de 120 días después del primer caso (entre el 7/11/2020 y el 25/7/2020), el R0 estimado será de 1.07 y alcanzará 0.23 % de habitantes infectados. En el peor de los casos, el pico estimado será de 4375 (IC del 95%: 4156-4594) y 825 (IC del 95%: 700-950) en el mejor de los casos. El mayor número estimado de casos y hospitalizaciones estará en el rango entre 20 y 39 años, el número de muertes será mayor entre los ancianos y más pronunciado entre ≥ 80 años.
Conclusión: este es el primer estudio con proyecciones para COVID-19 en un municipio fuera de las grandes capitales y demostró que el pico llegará tarde, por lo tanto, el municipio tendrá más tiempo de preparación y que las medidas de protección pueden reducir el número simultáneo de casos.

DESCRIPTORES: Estimación. Epidemias Número reproductivo basal. Coronavirus. SARS-CoV-2. Letalidad. Hospitalización.

INTRODUCTION

In 2020, a respiratory syndrome was described, presenting different characteristics from previously diagnosed syndromes (SARS-CoV, MERS-CoV), caused by a new microorganism initially called 2019-nCoV. It causes a more serious respiratory disease in populations at risk, such as adults over 60 years and people with comorbidities.[1–2] The virus was first identified in Wuhan, in the province of Hubei, China, in individuals exposed to a market of live animals and seafood. China's sanitary authorities reported a fast increase in the number of confirmed cases and many deaths due to this new disease, called COVID-19. Since the disease appeared in China, it soon started to be identified in other countries.[3]

On March 11, 2020, a pandemic was declared by the World Health Organization (WHO) due to the new coronavirus.[4] The Johns Hopkins University reported 2,744,511 global cases and 192,982 deaths by COVID-19 worldwide[5] until April 24, 2020, and the estimated lethality rate varied from 1.18% in Germany up to 12.07% in Italy.[6]

In Brazil, until April 23, 2020,49,492 cases had been reported, and a lethality rate of 6.7% for any age group. All regions of the country have confirmed cases and deaths by COVID-19, but distinct distribution, behavior and mortality rates are observed in the different Brazilian regions, with a greater number of confirmed cases and deaths in the Southeast and Northeast regions, respectively. On the same day, the South region presented the second lowest number of cases of COVID-19, behind the Central West region.[7] Paraná had 1,082 confirmed cases and a lethality rate of 5.5% on the same day.[8]

To control the pandemic, gradual social distancing was adopted in the country, but not simultaneously in all states, in addition to closed borders, investments in public health and health infrastructure, and hiring of new health professionals, among other actions. However, such measures were adopted in general at the national level, without taking into account local specificities and structures of states and municipalities.[9]

Considering Brazil in general and large centers such as São Paulo and Rio de Janeiro, studies have been conducted to find predictive models and help health services develop coping actions.[5,10–11] However, no studies have been developed showing estimated time and intensity of epidemic incidence for small and medium-sized municipalities. Given the need to implement measures for the prevention of virus dissemination and acquisition of patient care infrastructure, this study aimed to produce a predictive model for the disease incidence, severity and deaths by COVID-19 in 2020 in Ponta Grossa, a medium-sized municipality in the state of Paraná, Brazil.

METHOD

Study design

This is an ecological study that used data available on government digital platforms (as described below) without analysis on humans or animals; therefore, not requiring an assessment by a research ethics committee. An epidemic curve with an epidemiological model was built and the concepts, methods and scenarios evaluated are described as follows.

Data sources and study variables

Daily numbers of confirmed cases of COVID-19 in the municipality of Ponta Grossa were used from March 21, 2020 (when the first case was reported) to May 3, 2020, obtained from official public records of the Health Division of the State of Paraná.[8] A 'confirmed case' means a positive result in RT-PCR testing for COVID-19, or by clinical-epidemiological criteria, close contact at home with a laboratory-confirmed case, with fever and/or any respiratory symptom within 14 days after the last contact with the patient and for which specific laboratory investigation was not possible.[12] Therefore, the first 24 days of the epidemic were used as the primary input for the SIR (susceptible-infected-recovered) model described below. The population of Ponta Grossa considered in this study was 352,749 inhabitants.[13]

The following data were considered: 1.2% asymptomatic cases, 80.3% mild and moderate cases, 13.8% severe cases, and 4.7% critical cases, according to a descriptive study on COVID-19 cases in China published by the country's disease control center (CDC). Given the fact that it is the territory where the epidemic started and where the first epidemiological studies on the disease were published, and that the local CDC was used as the source, these were considered reliable data.[3] For the percentage of infected individuals, hospital admissions and deaths in each age group, an intense search was conducted in the literature and several studies were combined to obtain the parameters. These and other references are presented in detail in the Supplementary Material 1.

Statistical methods: SIR (susceptible-infected-recovered) epidemiological model

The model used in this study was developed by Kermack and McKendrick in 1927 and consists of explaining the behavior of an epidemic by dividing a population into 3 groups: susceptible (S), infected (I) and recovered (R); then, the model calculates the system of differential equations:[14]

$$\frac{dS}{dt} = -\beta \frac{I}{N} S$$

$$\frac{dI}{dt} = \beta \frac{I}{N} S - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

Where:

N= population of Ponta Grossa 2020[13]
S= number of susceptible individuals (all population was assumed as susceptible in the beginning of the epidemic)
I= number of infected individuals
R= number of recovered individuals
β= contagion coefficient
γ= recovery coefficient
t= time in days

Contagion and recovery coefficients were obtained by adjusting data (input) and by minimizing the total sum of squares (TSS) of the difference between the absolute number of infected individuals and the number of infected individuals adjusted from the system of differential equations above. The final values of β and γ were obtained by an iterative optimization process using the method developed by Byrd et al.[16] that allows restrictions on the parametric domain of data. This analysis is more robust for non-linear optimization problems than Monte Carlo simulations, for instance. In the end, the reproduction rate (R_0) was obtained, which is an estimated number of individuals infected by one infected person. The following values were then generated: SIR curves from the beginning to the end of the epidemic, estimated duration of the epidemic, estimated peak period, curve to estimate the number of cases over time, and percentage of infected individuals at the peak period.

Three scenarios were simulated to estimate the curves of expected cases:

Scenario 1: estimated curve based on confirmed data from the first 24 days (March 21, 2020 to April 13, 2020).
Scenario 2: estimated curve based on confirmed data from the first 34 days (March 21, 2020 to April 23, 2020).
Scenario 3: estimated curve based on confirmed data from the first 44 days (March 21, 2020 to May 3, 2020).

All statistical analyses were performed by the study authors using R software.[15]

RESULTS

There were 5 confirmed cases in the first 24 days since the first case reported on March 21, 2020 in the municipality, characterizing a cumulative incidence in the period of 1.42 cases per 100,000 inhabitants. Dispersion of cases over time and the estimated curve during the first 24, 34 and 44 days are illustrated in Figures 1A, 1B and 1C, respectively. The curves that best explained data variation in the three scenarios were exponential curves of r^2=0.74 (p<0.0001), r^2=0.79 (p<0.0001) and r^2=0.89 (p<0.0001), respectively. Variation in the scenarios showed a growing curve and decline of the growth angle over the period. The coefficient started at 0.069 and ended at 0.054; that is, the speed during the first days was more accentuated than the speed in the whole period.

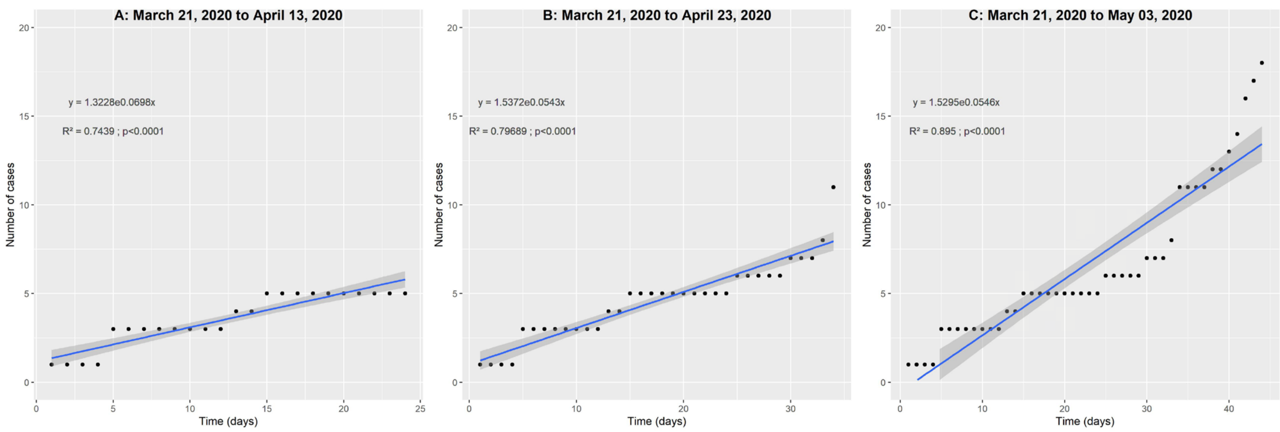

Figure 1 – Curves of confirmed cases during the first 24, 34 and 44 days of the COVID-19 epidemic (day 0 = March 21, 2020) in the municipality of Ponta Grossa, Paraná, Brazil, 2020.

A SIR model was built with data from the first 24 days of the disease and the city population (Figure 2A). The graph in Figure 2A starts on day 1 (March 21, 2020) with the susceptible population on the day the first case was reported (N - 1), number of infected individuals = 1 and number of recovered individuals = 0. Over time, a fluctuation occurred among susceptible, infected and recovered individuals, reaching its peak around 120 days after the first case, that is, between July 10, 2020 and July 24, 2020, and a balance after about 170 days, with zero infected individuals and N = recovered + susceptible individuals. At the end of the period, the reproduction rate (R_0) of the municipality would be 1.18 and, at the peak, it would infect around 1.24% of the population. Figures 2B and 2C show the SIR models generated for the first 34 and 44 days. The reproduction rate would be 1.14 and 1.07, respectively, and would infect 0.88% and 0.23% of the population at the peak. Given that the real exponential growth of cases at day 44 was slower than in the first 24 days, it also impacted the estimates of the SIR model.

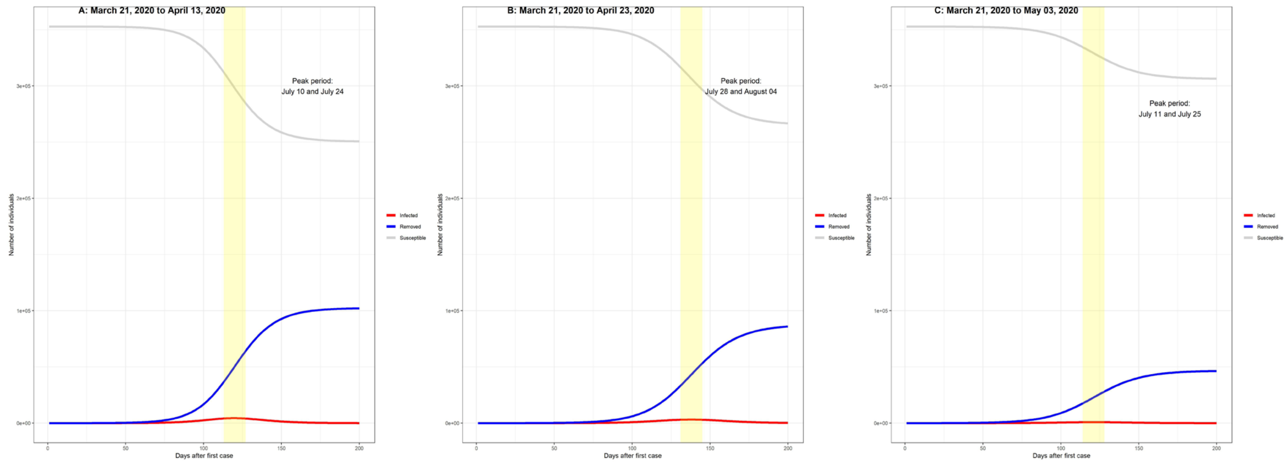

Figure 2 – Estimates generated by the SIR (S = susceptible, I = infected and R = recovered) model for 200 days of the epidemic based on confirmed cases during the first 24, 34 and 44 days of the COVID-19 epidemic (day 0 = March 21, 2020) in the municipality of Ponta Grossa, Paraná, Brazil, 2020.

Figure 3 shows the estimates for the simulation of three scenarios regarding the total number of cases – mild and moderate, and severe and critical cases. The scenario with data from the first 24 days was the worst scenario, with an estimated peak of infected individuals of 4,375 (5% lower, corresponding to 4,156, and 5% higher, corresponding to 4,594), of these,3,513 (±5%, 3338 -3689) were mild and moderate cases, and 809 (±5%, 769-850) were severe and critical cases. The scenario with data from the first 34 days was an intermediate scenario, with an estimated peak of infected individuals of 3,117 (±5%, 2961-3273), of these,2,503 (±5%, 2378-2628) were mild and moderate cases, and 577 (±5%, 548-605) were severe and critical cases. The scenario with data from the first 44 days was the best scenario, with an estimated peak of infected individuals of 825 (±5% 783-866), of these, 662 (±5%, 629-695) were mild and moderate cases, and 153 (±5%, 145-160) were severe and critical cases. Along the first 44 days of the epidemic, it slowed down when compared to estimates at the beginning of the epidemic.

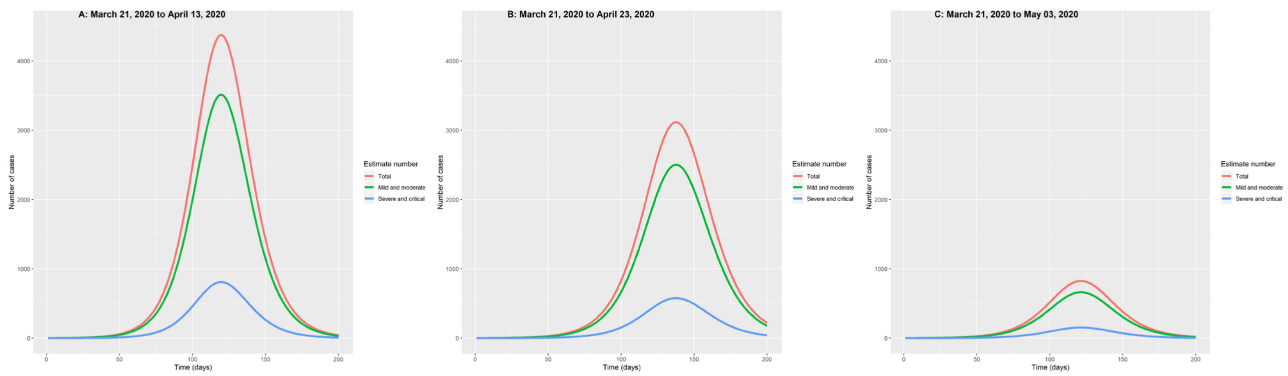

Figure 3 – Graphs of the SIR model showing estimated numbers of COVID-19 cases, with the total number of cases (red curve), number of mild and moderate cases (green curve) and severe and critical cases (blue curve) in three scenarios: confirmed cases during the first 24, 34 and 44 days of the COVID-19 epidemic (day 0 = March 21, 2020) in the municipality of Ponta Grossa, Paraná, Brazil, 2020.

In all scenarios estimated by age group (Table 1), the highest number of cases and hospital admissions due to COVID-19 were calculated for the 20-29 and 30-39 age groups. However, the estimated absolute number of deaths was higher among the elderly, and the number of deaths among the oldest group (≥80 years), in all scenarios, was higher than the number of deaths in the age group of 40 years, and at least twice the number of individuals aged 70-79 years.

Table 1 – Estimated peak of COVID-19 cases in each age group and 95% confidence interval (95% CI) in the three scenarios: confirmed cases in the first 24, 34 and 44 days of the COVID-19 epidemic (day 0 = March 21, 2020) in the municipality of Ponta Grossa, Paraná, Brazil, 2020.

Age groups	Scenario 1	Scenario 2	Scenario 3
0-9	13 (0-27)	9 (0-19)	2 (0-5)
10-19	80 (44-116)	57 (32-83)	15 (8-22)
20-29	1039 (925-1152)	740 (659-821)	196 (174-217)
30-39	1140 (1023-1257)	812 (729-896)	215 (193-237)
40-49	688 (591-785)	490 (421-560)	130 (111-148)
50-59	507 (421-592)	361 (300-422)	96 (79-112)
60-69	401 (324-478)	286 (231-341)	76 (61-90)
70-79	287 (221-353)	205 (158-252)	54 (42-67)
≥ 80	220 (161-278)	156 (115-198)	41 (30-52)
Total: cases	**4375 (3713-5039)**	**3117 (2645-3590)**	**825 (700-950)**
0-9	4 (0-8)	3 (0-6)	1 (0-2)
10-19	24 (13-35)	17 (10-25)	5 (3-7)
20-29	312 (278-346)	222 (198-246)	59 (52-65)
30-39	342 (307-377)	244 (219-269)	64 (58-71)
40-49	207 (177-236)	147 (126-168)	39 (33-44)
50-59	152 (126-178)	108 (90-127)	29 (24-33)
60-69	120 (97-143)	86 (69-102)	23 (18-27)
70-79	86 (66-106)	61 (47-75)	16 (13-20)
≥ 80	66 (48-83)	47 (35-59)	12 (9-16)
Total: admissions	**1313 (1114-1512)**	**935 (794-1077)**	**247 (210-285)**
0-9	0 (0-0)	0 (0-0)	0 (0-0)
10-19	0 (0-0)	0 (0-0)	0 (0-0)
20-29	1 (0-4)	1 (0-3)	0 (0-1)
30-39	3 (1-4)	2 (1-3)	1 (0-1)
40-49	3 (2-3)	2 (2-2)	1 (0-1)
50-59	6 (4-8)	4 (3-6)	1 (1-2)
60-69	14 (14-15)	10 (10-11)	3 (3-3)
70-79	16 (8-47)	11 (5-34)	3 (1-9)
≥ 80	36 (19-53)	26 (14-38)	7 (4-10)
Total: deaths	**80 (49-136)**	**57 (35-97)**	**15 (9-26)**

DISCUSSION

This is the first study to characterize COVID-19 projections for a municipality that is not a large capital city of Brazil. The characteristics of this municipality are similar to the reality of many others; therefore, the methodology used in this study can be adapted and extrapolated to other locations. The municipality population is 352,749 (fourth in the state of Paraná), covering an area of 2,055 km^2, with a demographic density of 171.6 inhabitants/km^2.[13] According to the Brazilian Institute of Geography and Statistics (IBGE), medium-sized municipalities are those with a population between 100,000 and 500,000; therefore, this classification includes 276 municipalities in Brazil, along with Ponta Grossa, the 22nd in Paraná.[17]

In terms of number of cases and cumulative incidence, Ponta Grossa was below Curitiba and São Paulo, where at day 24, the incidence was 5.89 and 8.89 cases/100,000 inhabitants, respectively, and similar to the state of Paraná in general, where the incidence was 2.52 cases/100,000 inhabitants in the same period.[8,10] This result points to the need for differentiated and proportional estimates that take into account the characteristics of municipalities other than large centers.

Although the small number of cases and low cumulative incidence may indicate a small magnitude of the disease in the municipality, the proportional approximation to the exponential curve in all scenarios shows that, despite the specificities, the variation of cases will be similar to what has been reported in other realities. The behavior of the epidemic in the first stage with exponential growth was also found in several other locations in Brazil and worldwide.[5,15,18–20]

The estimated peak of disease cases after around 120 days in all scenarios may indicate the municipality will have more time to adopt measures to handle the disease than other municipalities and that the measures adopted in the first 44 days may have delayed its incidence. In China, the peak period of the disease was observed around 90 days after the first case was reported.[21] In Brazil, a study using the same SIR model estimated that in the state of São Paulo, the peak period would be within around 70 days, and in Minas Gerais Gerais and Rio de Janeiro, within about 60 days.[11] Therefore, large cities may present a decline in the epidemic curve, when medium-sized municipalities, such as the one analyzed in this study, will have an increase in cases, admissions and deaths.

While these municipalities will have an opportunity to prepare for the disease dissemination and complications, they will face an increasing incidence of COVID-19 concomitant with the respiratory infections that cyclically appear in winter season. However, regional services that offer health care to more serious cases, including COVID-19 and other respiratory complications caused by infections, are generally located in medium-sized municipalities, so if the predicted scenarios become a reality, they will take place with situations observed every year and which overload the health services in these locations. In this case, surveillance and prevention and planning efforts are highly important, not only for COVID-19, but to ensure a proper response to what has been anticipated for the next months.

Reproduction rates (R_0) of 1.18, 1.14 and 1.07 were below those estimated in other national and international studies. In a study published by the response committee of Imperial College London with an estimated incidence of COVID-19 for several countries, including Brazil, R_0 ranged from 2.5 in Denmark to 4.8 in Spain.[22] For Brazil, estimates ranged from 1.4 in Rio de Janeiro to 2.6 in Ceará. The number obtained for Ponta Grossa was also reflected in the final proportion of infected individuals of 1.24%, which for other states, ranged from 5.23% in Rio Grande do Sul to 20.5% in Ceará.[11]

In addition, flattening the curve over time may be related to an increase in the number of infected, recovered or immune individuals, a trend already observed in other viral infections. That is, as the epidemic increases and more people are ill and recover, R_0 tends to decrease.

When analyzing the behavior of estimated data and simulations with a reduced peak, the focus is on predicting urgent hospital needs for the period and reducing the number of deaths. However, the initial protocol of the Ministry of Health of Brazil must be considered, according to which only hospitalized patients were tested.[23] In view of the above, the number of confirmed cases would represent only 30% of the actual infected individuals, as demonstrated in another study.[24]

The limitations of this study refer to estimates based on a simplified traditional epidemiological model (SIR), assuming the behavior of cases during the first days and the estimated population of the municipality. In addition, the scenarios were developed using the parameters of proportion of mild, moderate, severe, and critical cases, hospital admissions and deaths present in the literature until the moment of publication. A systematic review with a critical analysis of the predictive models for COVID-19 published between January and March 2020 analyzed the results of 10 predictive models for progression and mortality. The main factors for bias in estimated numbers were: absent demonstration of equations, incomplete description of assumptions and inadequate exclusion of portions of the population.[24] In this study, the equations were summarized in the section of material and methods and presented in detail in the references; all parameters of the simulations are presented in the supplementary material 1, and no portion of the population was excluded for the calculations. However, despite considering the limitations and probability of bias in the estimates presented in this study, this study is relevant due to its (not exact) approximation to the reality that may be experienced in other municipalities in Brazil.

To elucidate the assumptions that could change the scenarios, Figure 4 contains the facts used in the calculations of this study and an illustrative summary of the assumptions causing changes in the scenarios. The effects of protective measures and their impact on the current pandemic in Brazil were also discussed in a recently published documentary study showing the evolution of curves in Brazil and other countries with and without protective measures.[25]

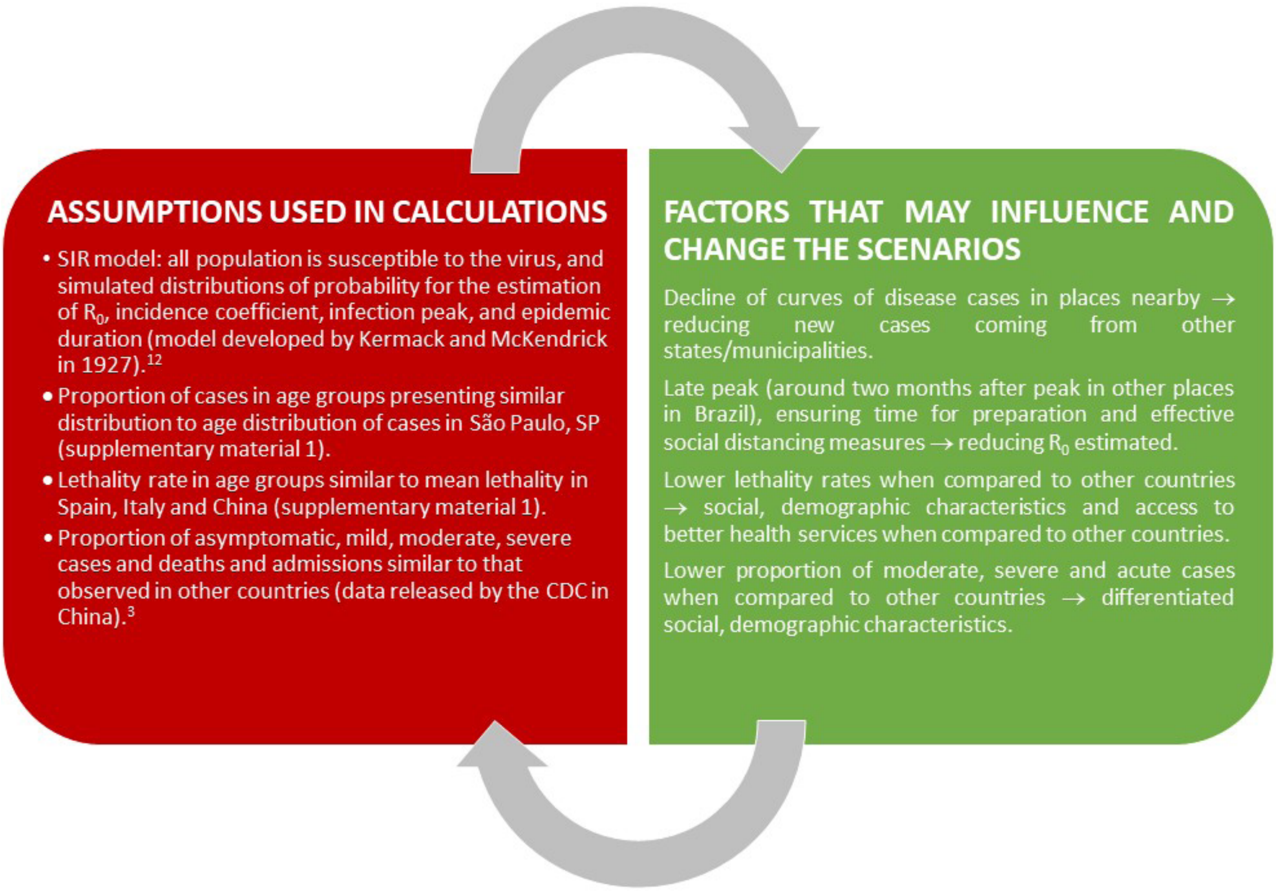

Figure 4 – Summary of facts used in the calculations of the predictive models for COVID-19 incidence and factors that could influence and change the scenarios anticipated for Ponta Grossa, Paraná, Brazil.

CONCLUSIONS

The total incidence of COVID-19 in Ponta Grossa in the first 44 days of the disease was lower than in large centers and, despite this, the increase in cases can be explained by an exponential curve, just like other locations. According to this study, the peak period will occur around 120 days after the first case and almost four months after the beginning of the epidemic in Brazil. At the end of the period, R_0 of the municipality will be 1.07, also below other locations in the world, and at the peak period it will infect about 0.23% of the population.

A reduced number of cases due to protective measures can reduce the simultaneous burden of care for critically ill and severe patients; however, the model takes into account many facts and, when a change occurs, there may be a variation in the estimated scenarios. Anyway, this study showed that the municipality will have more time to prepare and implement actions, and it can be extended to other municipalities of the same size.

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NOTES

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ACKNOWLEDGEMENTS

The authors would like to thank the State University of Ponta Grossa, Fundação Municipal de Saúde - Prefeitura Municipal de Ponta Grossa, and AAC&T Consultoria em Pesquisa LTDA.

CONFLICT OF INTEREST

None.

HISTORICAL

Received: May 06, 2020.
Approved: June 15, 2020.

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