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Assessing and implementing a test, trace, isolate and face mask-wearing programme to reduce SARS-CoV-2 transmission in Queretaro, Mexico: a mathematical modelling approach.

Evaluación e implementación de un programa de pruebas, rastreo, aislamiento y uso de cubrebocas para reducir la transmisión del SARS-CoV-2 en Querétaro, México: un enfoque de modelado matemático

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Abstract

Non-pharmacological interventions stood as the only severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) morbidity and mortality mitigation tools before vaccines were made available. Some, such as strict "stay-at-home" strategies, posed significant adherence, compliance and sustainability challenges because of social, economic, and psychological factors. Following relaxation of strict social distancing measures, Test, trace and isolate (TTI) strategies sought to mitigate viral spread via self-isolation and quarantine through early detection of infectious people. Mathematical modelling can contribute insight into emergency responses by examining possible scenarios and their impact on morbidity, mortality and public health system capacity. This paper describes the use of mathematical modelling to assess the impact of a test, trace, isolate and face mask-wearing programme to reduce SARS-CoV-2 transmission in Queretaro. This model was developed by Oxford University and implemented during the COVID-19 emergency to inform the Health Security Committee in Queretaro. Describing the implementation of mathematical modelling in the field may be valuable to strengthen preparedness and response plans for other potential future pandemics.

KEYWORDS: SARS-CoV-2, COVID-19, pandemics, preparedness and response

Resumen

Las intervenciones no farmacológicas representaron medidas centrales para mitigar los riesgos ante la emergencia por el coronavirus tipo 2 causante del síndrome respiratorio agudo grave (SARS-CoV-2) a nivel mundial. Estas medidas implementadas poblacionalmente atenuaron el número de casos y hospitalizaciones por casos graves de la enfermedad antes de la introducción de vacunas específicas. Algunas estrategias como la de "quédate en casa" plantearon desafíos sociales, económicos y psicológicos importantes que limitaron su uso a largo plazo. Por otro lado, la estrategia de detección y rastreo de casos y contactos buscó reducir la posibilidad de otros contagios mediante autoaislamiento y cuarentena. El modelaje matemático puede contribuir a la respuesta ante emergencias en salud pública mediante

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la simulación de posibles escenarios y su impacto en morbilidad, mortalidad y la capacidad del sistema de salud pública. Este artículo describe el uso del modelaje matemático para explorar el potencial impacto de la estrategia de uso de cubrebocas, detección y rastreo de casos y contactos en la capacidad hospitalaria. El modelo fue desarrollado por la Universidad de Oxford e implementado durante el periodo de la emergencia por COVID-19 para informar al Comité de Seguridad en Salud en el Estado de Querétaro. La descripción de la implementación de modelaje matemático en campo podría ser de gran valor para fortalecer los planes de preparación y respuesta ante futuras pandemias.

PALABRAS CLAVE: SARS-CoV-2, COVID-19, pandemias, preparación y respuesta.

POPULATION-WIDE MEASURES TO TACKLE SARS-COV-2

Non-pharmacological interventions (NPIs) were shown to be effective in reducing the incidence and the healthcare demand early in the course of the SARS-CoV-2 epidemic[1-5,] but highly disruptive measures such as nationwide lockdowns also resulted in detrimental consequences for health delivery and socio-economic areas which challenged their sustainability in Mexico. [6,7] For this reason, it was reasonable to advocate for having a more balanced approach to cope with SARS-CoV-2 while protecting essential health services and economic activities, especially across low and middle-income countries (LMIC), where health systems and financial resources historically have faced significant gaps.[8,9]

Test, trace and isolate (TTI) strategies gained visibility to suppress the virus during the relaxation of major mobility disruption measures because they represented a feasible strategy for early identification of cases or clusters of SARS-CoV-2, and reduce dispersion through isolation of cases and the quarantine of contacts.[10] Modelling studies played a significant role in estimating the impact of TTI strategies throughout the course of the COVID-19 pandemic,[2,4] but less is known about how mathematical simulations were reasonably translated into policy practice. Here, we describe the use of a mathematical model to assess the potential impact of increasing the coverage of TTI strategies in the state of Queretaro, Mexico, in the context where economic activities were partially lifted.

THE SARS-COV-2 EMERGENCY RESPONSE IN MEXICO- FROM THE NATIONAL TO THE LOCAL APPROACH

The National Surveillance System incorporated the diagnosis of SARS-CoV-2 early in 2020. Suspected cases included people who presented cough, fever or headache, in addition to at least one of the following manifestations: breathlessness, arthralgia, myalgia, sore throat, rhinorrhoea, conjunctivitis or chest pain during the last 7 days. [11] RT-PCR tests were recommended to perform for at least 10% of outpatients and 100% of hospitalised cases or deaths identified by healthcare facilities. However, this 10%

proportion of testing to identify mild cases was greater according to test availability and local financial resources. The sensitivity of this epidemiological system facilitated the detection of the first imported case of SARS-CoV-2 in February [12] and the subsequent community transmission in March when Mexico declared the epidemic of SARS-CoV-2 a public health emergency.[13]

During March and April, comprehensive measures were implemented to mitigate the effects of SARS-CoV-2 such as social distancing, school closures, working at home, handwashing, covering coughs and sneezes, cleaning surfaces and self-isolation in case of symptoms.[14] Based on nine response indicators, the Government Response Stringency Index rose from 8.33 on the 21st of March to 82.41 on the 30th of April 2020.[15] On the 30th of May, the National Strategy of Social Distancing was finished because of spatial differences in SARS-CoV-2 incidence and deaths across 32 states, **(Figure 1)** and a colour scheme was developed to trace epidemiological risks at the state level and subsequently guide the local reopening of non-essential activities.[16,17]

This unprecedented emergency required comprehensive local responses, including coordination of multidisciplinary teams, risk communication, surveillance and case investigation, public health laboratory, operational support, and maintenance of health care delivery. The conversation regarding which strategies were best for coping with this ongoing crisis opened the possibility of using mathematical modelling to inform subnational policies.

MODELLING THE SARS-COV-2 RESPONSE TO SUPPORT DECISION-MAKING

In Queretaro, a state with more than 2.2 million people in the central region of Mexico, we used an age-structured SEIR [Susceptible, Exposed, Infectious, Recovered] model of SARS-CoV-2 transmission to influence decision-making in the context of the local epidemic response.[18] The mathematical model was developed by the Oxford-led COVID-19 Modelling (CoMo) Consortium Modelling Group through a participatory process of knowledge production between international modellers, a core group of national public health professionals, and local policymakers across 42 different countries. [19,20]

Real-time modelling analyses and reports followed the recommendations for good practice of the Society for Medical Decision Making.[21] This approach encouraged the active participation of multidisciplinary teams, integrated by clinicians, planners, policymakers, and a group of public health professionals **(Figure 2).** Early in the response, the Health Security Committee in Queretaro engaged with the CoMo Consortium to critically appraise real-world questions regarding the potential impact of NPIs on the epidemic curve and hospital occupancy. The model was regularly calibrated to reported cases and deaths associated with SARS-CoV-2 according to the National Surveillance System[18] through several iterations between the national core team and the Consortium. Data was fitted and discussed using an online interface, available at https://comomodel.net, which offered a user-friendly interface for non-expert users at the local level. Scenarios were discussed and customised according to the research questions and policy priorities. To address uncertainty regarding social mobility, google trends were used to estimate the coverage of social distancing measures and working at home within the community over the relevant time periods.

FITTING THE MODEL

The model was fitted by matching RT-PCR confirmed cases and deaths reported to the SARS-CoV-2 surveillance system. **(Figure 3)** For example, from the 5th of March, when the first case was confirmed, to the 30th of September, Queretaro confirmed 9,802 cases and

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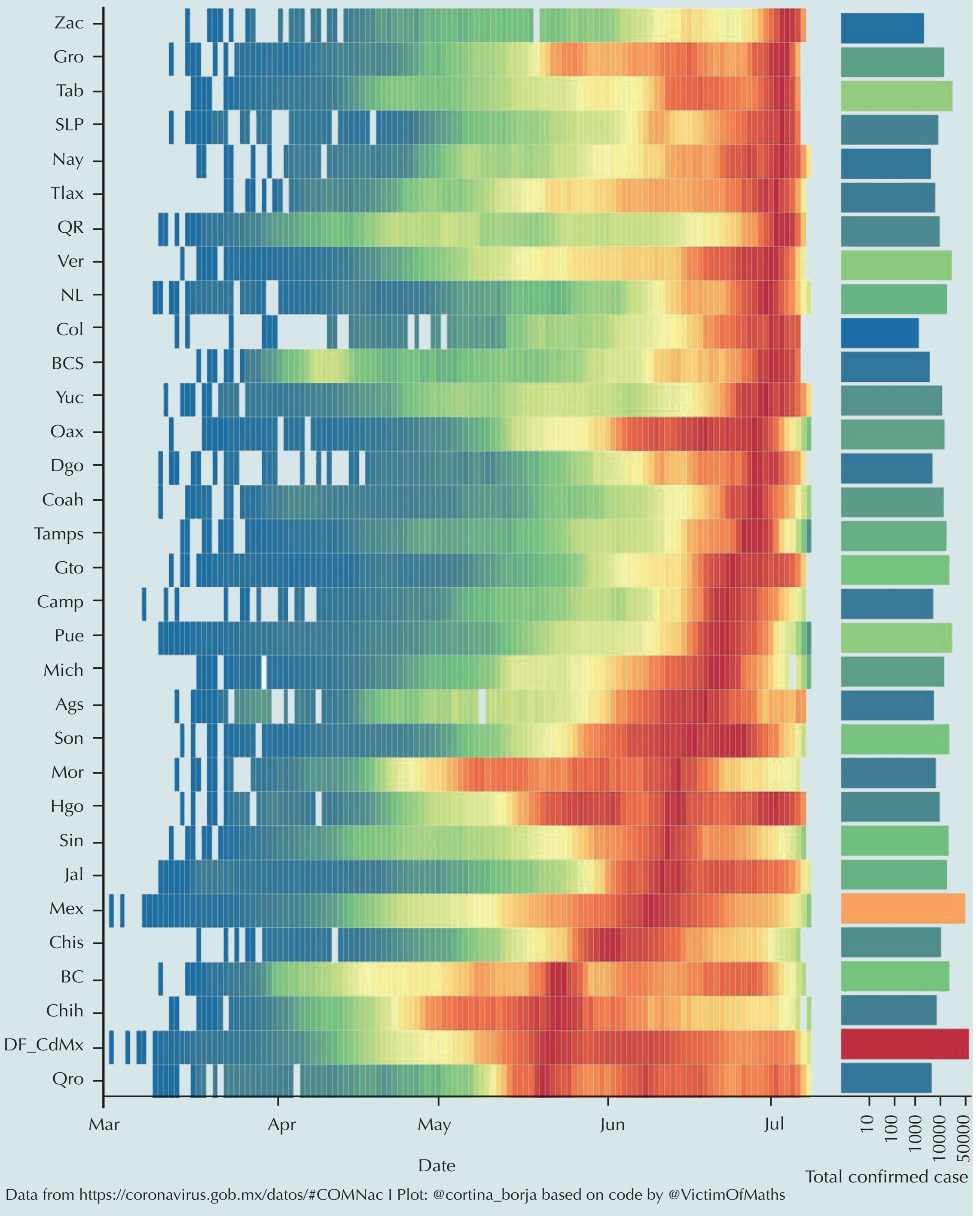

Figura 1. Heatmap with a 7-day rolling average of new confirmed cases. Each row represents one state. Bars represent the absolute number of cases in each state. Source: Ministry of Health[18]

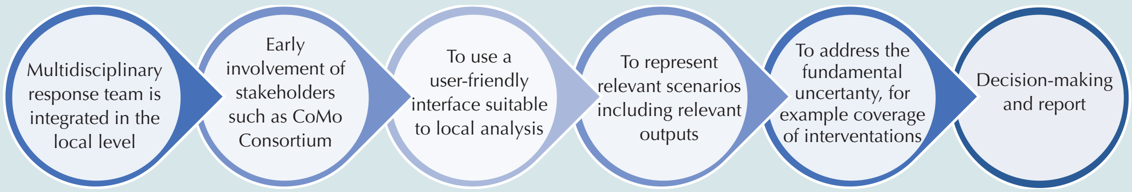

Figura 2. Process for modelling SARS-CoV-2 in Queretaro during 2020. Adapted from Brandeau ML (2009)[21].

963 deaths associated with SARS-CoV-2, with a positivity of 43.1% during the epidemiological week number 40.[18] Cases and deaths were organised according to the onset of symptoms and the day of occurrence, respectively. The simulation period started on the 29th of February and ended on the 31st of December 2020. Social distancing and working at home were estimated according to mobility trends from the 18th of March; these figures are estimated for the state of Queretaro compared with the reference for the same population.[22]

MODELLED SCENARIOS

We estimated the impact of implementing TTI strategies on the epidemic curve and hospitalisations from October 1st in Queretaro. We considered hospital occupancy a crucial output because it offered the advantage of anticipating healthcare workers' workload and planning hospital reconversion for COVID-19 and non-COVID-19 medical conditions.

To address a range of feasible policy interventions, we modelled scenarios with different TTI coverages (20%, 40% and 60% compared to no TTI), making three main assumptions: 1) that the social mobility would be constant from the last estimation available to the end of the period of observation, 2) that schools would remain closed for the rest of the year, and 3) that cases and contacts would follow the self-isolation and quarantine counselling during 14-days. Our first assumption was based on the 20% reduction in mobility in public spaces and workplaces reported until the 30th of September.[22] This theory was challenged by holidays and national days such as those celebrated on the 16th of September, the 1st and 2nd of November, the 12th of December, and Christmas time, when people tend to gather. Our second assumption was supported by current guidelines from the Ministry of Health and the Ministry of Education, which recommend reopening schools until the epidemiological risk is low.[11,23] Our third assumption was based on recommendations from the World Health Organization for quarantine and isolation, which aimed to prevent associated illness and fatal complications by slowing viral transmission.[10]

RESULTS FROM TRANSMISSION SCENARIOS

Compared to no TTI, all scenarios effectively reduced hospital occupancy from the 1st of October, when the strategy was planned to be implemented **(Figure 4).** According to our hypotheses, the coverage of ITT strategies influenced the number of severe cases over the observed period. Even though the implementation of ITT strategies did not exceed the existing capacity of 754 standard (surge) beds, 280 ICU beds, and 248 beds with a ventilator for the rest of the year, the scenario with a low 20%

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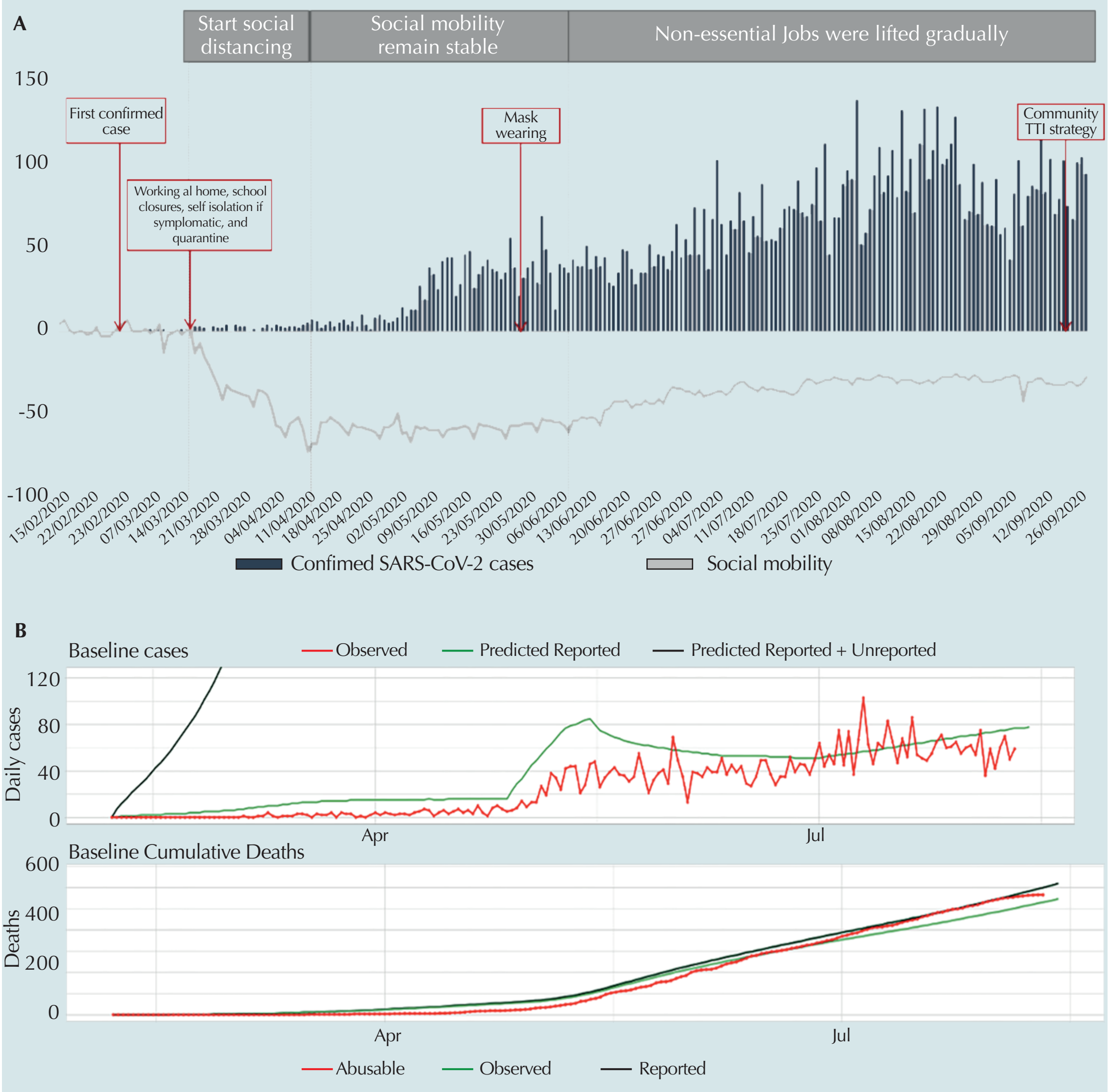

Figura 3. Input data to fit the model. **(A)** Number of SARS-CoV-2 confirmed cases, social mobility and NPI implemented in Queretaro, Ministry of Health[18]. **(B)** Panel with the fit of the model. Red lines represent epidemiological data, and green lines represent predicted data based on daily cases and deaths.

coverage showed a growing trend reaching 240 occupied beds during the second week of December. On the other hand, ITT coverage from 40% onwards showed a reduction in hospital occupancy by the rest of the year.

THE EPIDEMIOLOGICAL PICTURE AND CHALLENGES

During the period studied in this paper, Queretaro confirmed 19,518 cases (856 cases per

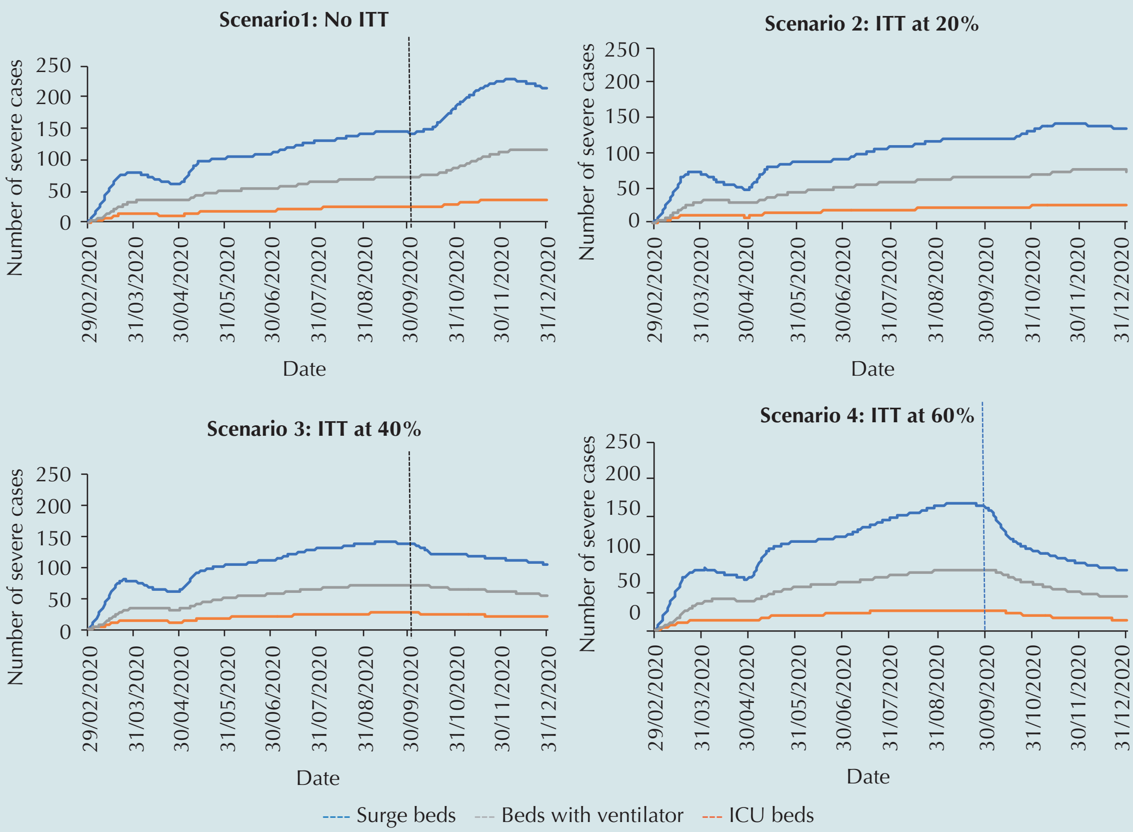

Figura 4. Number of severe cases hospitalised according to types of beds. Queretaro, February to December 2020 .

100,000 inhabitants) and 1,360 deaths (59 deaths per 100,000 inhabitants) associated with SARS-CoV-2, with a 44.1% positivity during the epidemiological week number 46.[18] Looking at the data, RT-PCR confirmed cases showed an increasing trend from the 1st of October, when the strategy started, from around 100 to nearly 200 SARS-CoV-2 cases per day **(Figure 5).** This trend was mainly related to outpatients rather than severe cases. However, when we estimated SARS-CoV-2 cases adjusting for the number of tests performed over time and then standardise per 1,000 tests performed, the trend for hospitalisations was likely to increase, and the trend for outpatients was lower compared to mid-August. The analysis of both crude and standardised cases per tests performed provided a more accurate understanding of trends in the epidemic curve, supported policy decisions and avoided implementing additional restrictions in Queretaro. [24]

FIELD INVESTIGATION AND COMMUNITY ENGAGEMENT

The field investigation followed a community-based approach which was highlighted as a feasible appraisal for low- and middle-income settings coping with SARS-CoV-2.[25] We followed WHO recommendations to investigate suspected cases with proper testing, isolation, and quarantine of contacts to contribute to controlling and preventing further cases and medical complica-

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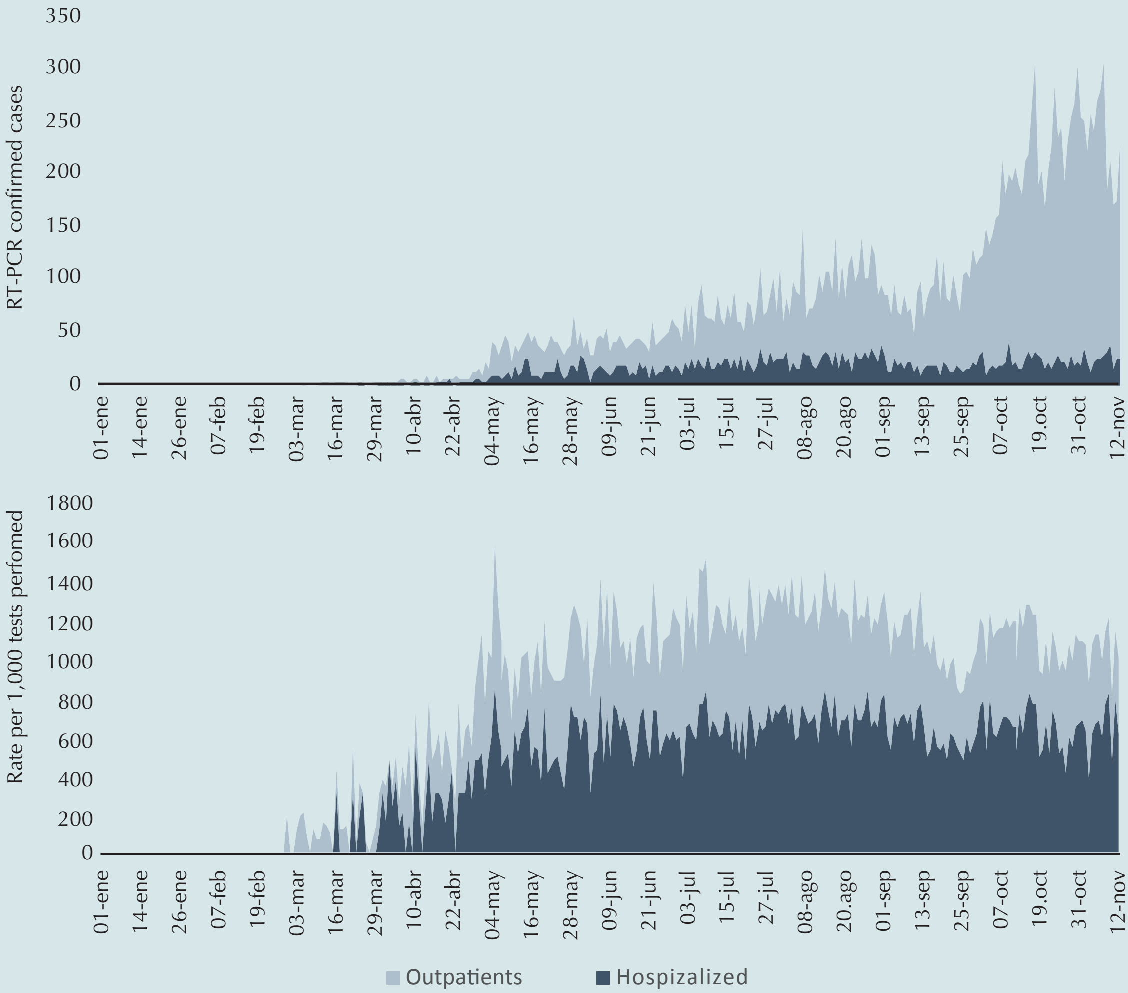

Figura 5. RT-PCR confirmed cases and estimated rate per 1,000 tests performed in Queretaro according to the type of patient, Jan-Nov 2020. Adapted from Henegan, 2020.

tions.[10] We took advantage of the experience gained approaching other infectious diseases to actively detect and trace transmission chains within the community, changing the passive diagnosis of cases in healthcare facilities from the active mobilisation of healthcare workers.[26] Community health workers were trained and supplied with personal protection equipment to minimise the risk of infection. A call centre identified suspected cases. Two community health workers visited the household to investigate cases and close contacts. During the visit to the household, they interviewed people with suspected cases, traced close contacts, collected respiratory specimens and identified potential medical complications.[10] A first-aid package was provided, including face masks, hand sanitiser and acetaminophen.

MODELLING, POLICY PRACTICE AND SUBSEQUENT IMPLICATIONS

In Queretaro, the active participation of relevant actors from the Health Security Committee at each stage of the modelling process ensured that the epidemiological data were reliable to address relevant policy questions. Modelling suggested that the implementation of a test, trace, isolate and mask-wearing strategy in Queretaro was able to affect COVID-19 transmission. Maintaining these strategies, alongside the decision to lift restrictions for non-essential jobs, was predicted to preserve hospital capacity and palliate economic constraints, even with a conservative TTI 20% coverage. Using these predictions, we also anticipated the number of laboratory supplies needed to test cases and contacts throughout the period of observation.

As part of the follow up, we also analysed how hospitalisations changed over time. Figure 6 shows the number of hospitalisations notified by epidemiological week and the proportion of patients who needed medical care in Intensive care units, mechanical ventilation, and deaths. The number of hospitalisations slightly increased from week 42. Additionally, the proportion of patients who required mechanical ventilation or medical care in intensive care units decreased from week 43. Then, this data suggested that the TTI strategy encouraged people from the community to seek specialised attention at the early stages. This would indicate that this strategy positively impacted the proportion of beds occupied in ICU and ventilators but not in beds with oxygen.

Finally, these results suggested that if hospitals did not exceed their capacity, the State could partially reconvert standard beds to avoid future disruptions in non-COVID-19 medical conditions. **Figura 6**

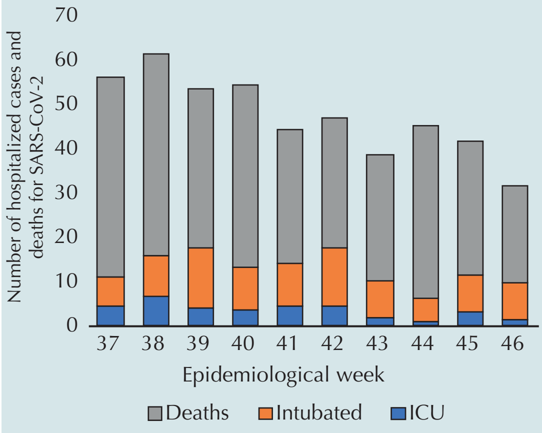

Figura 6. Severe cases of SARS-CoV-2, including deaths intubated cases and ICU patients in Queretaro, notified during epidemiological weeks 37-46, SSA, 2020.

CONCLUSION

We used mathematical modelling throughout the emergence of SARS-CoV-2 to assess the implementation of non-pharmaceutical measures in Queretaro, focusing on maintaining health system capacity. We recognise the value of linking modelling-derived information with policy decision-making, considering that the quality and timeliness of information are crucial. Future emergency responses to epidemics need to strengthen epidemiological surveillance and analyse modelling results in interaction with policymakers from relevant disciplines for operational translation. Community engagement can enable a better understanding of population dynamics and communication to build trust.

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