Use of fever screening and quarantine in Lagos to curtail the COVID-19 outbreak following lockdown: a modeling study

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Abstract

Objectives: With an estimated population of more than 20 million, Lagos State is one of the world's most populous urban areas. On March 30, 2020, Lagos State began a 5-week lockdown in an attempt to curtail the spread of SARS-CoV-2 among the population. Phase-out of the lockdown began on May 4, 2020 despite rising cases of COVID-19. With cases continuing to rise, estimating the impact of the lockdown, and what policies could minimize the chances of another one, is an immediate priority.

Design: We use an agent-based COVID-19 model to simulate a population representative of Lagos State. We estimate the effect of the April lockdown and simulate the likely evolution of the epidemic over the second half of 2020 under different assumptions about the extent of fever screening in public places, assuming that mobility increases to pre-lockdown levels.

Results: We estimate that around 80,000 people in Lagos State had been infected with COVID-19 by the end of June 2020. Without the lockdown, the number of infections would have been much higher; we estimate that up to a quarter of the population could have been infected by the end of June in the absence of interventions. Depending on the sensitivity of fever screening (10–50%) and the proportion of the adult population that could be screened over the second half of 2020 (10–50%), we estimate that screening could avert up to 85% of infections by the end of 2020.

Conclusions: With the supply of PCR tests in Lagos unlikely to be high enough to diagnose enough cases for epidemic control, fever screening may be an alternative policy that would help mitigate the spread of SARS-CoV-2, but it is unlikely to be sufficient to control the epidemic.

Article summary

Strengths and limitations of this study

- This study presents the first estimates of the scale of the COVID-19 epidemic in Lagos.
- In addition to epidemic estimates, the model that we use can also quantify the effect of the lockdown that was imposed in Lagos over April, as well as estimate the potential role of fever screening in curtailing the spread of the virus in the absence of physical distancing restrictions.
- However, considerable uncertainty remains regarding the true size of the COVID-19 epidemic in Lagos, due to the high likelihood of significant underreporting of both cases and deaths.

Introduction

More than 10 million cases of COVID-19 had been reported globally as of June 30, 2020. Approximately 50% of those were located across the Americas, 27% in Europe, and 18% across Asia and the Eastern Mediterranean, while less than 3% were located in Africa. However, the scope for an outbreak in African nations is of immediate concern: a combination of under-resourced health systems, high prevalence of conditions associated with higher COVID-19 mortality (e.g., hypertension and diabetes), and the potential for rapid transmission within closely-integrated communities mean that the impact of COVID-19 could rapidly become catastrophic. [1-3]

Lessons learned from the evolution of the COVID-19 pandemic indicate that the majority of cases tend to be concentrated in densely-populated urban centers (e.g., New York City). With an estimated population of 20 million, Lagos is the largest city in Africa, and the state in which it is located (Lagos State) is one of the world's most populous urban areas. Predicting the likely evolution of the epidemic in Lagos State is therefore a high priority.[4, 5]

The first confirmed case of COVID-19 in Lagos State occurred on February 27, 2020, and as of June 30, 2020, there were 10,310 confirmed cases (although the actual number of cases is likely to be much higher [6]). As part of its initial response, the Nigerian Federal government instituted a 5-week lockdown of Lagos State from March 30, 2020: citizens were ordered to stay in their homes, travel to or from other states was banned, and non-essential businesses and offices were closed. The lockdown measures began easing from May 4, 2020 in response to increased public pressure; many were unable to comply with the lockdown due to their personal or financial circumstances, and attempts to enforce the imposed measures led to the loss of several lives.[7-9] As part of this second phase of the response, various measures were put in place including mandatory use of face masks in public, mandatory provision of handwashing facilities/sanitizers, extensive temperature checks in all public spaces, physical distancing restrictions, and a nationwide curfew from 10pm to 4am.

Given the considerable uncertainty around the official reports of the numbers of cases and deaths in Nigeria,[10] there is scope for epidemiological modeling to assist with quantifying the likely trajectory of the COVID-19 epidemic in Lagos State under different policy settings. To date, many such models have been applied in different global contexts,[11, 12] but fewer studies have focused on Africa, [4, 5, 13-15] and even fewer have examined the feasibility and effect of COVID-19 mitigation policies in African settings. [16, 17] Such mitigation policies, which include physical distancing, isolation, testing, contact tracing, quarantine, and the closing of businesses and schools, have enormous consequences on the people and economies of the countries where they are implemented, so it is critical that decision-makers have the best possible information on which policies to implement and for how long in order to achieve the greatest impact with minimal disruption to their society and economy. It is also critical that the rollback of such policies is done in a way that does not compromise overall epidemic control.

The next phases of Lagos State's response are intended to emphasize testing and contact tracing measures while allowing the restoration of some economic and business activities in certain sectors.[7] However, there are concerns about testing capacity for COVID-19 in Africa[18] and whether it will be sufficient to form the basis of a broad-based containment strategy. It is therefore crucial that the limited tests available are optimally distributed in order to maximize yield and minimize the number of people in quarantine. Quarantining only the people most likely to have COVID-19 would provide most of the benefits of isolation without the economic impact of a city-wide lockdown.

We apply an agent-based model of COVID-19 to Lagos in order to assess the potential for symptom-based (fever) screening followed by quarantine to supplement testing over the remainder of 2020. Fever has been reported as one of the most common symptoms associated with COVID-19 cases, although estimates of the percentage of all cases that are accompanied by fever vary greatly.[19-21] Screening the general population for fever may be a cost-effective way to identify potential cases, but will depend on the sensitivity of fever screening and the extent to which it could be implemented. We demonstrate that such a policy could partially stem epidemic spread in the short-term, but will not be sufficient to curtail the epidemic.

Methods

Demographics and networks

We begin by creating a model of the population of Lagos State. We take data on the age and sex composition of the population from the 2006 census (the latest available), and use this to create 500,000 agents, each of whom is assumed to be representative of 40 people in the population, resulting in the total population of 20 million. For example, a single agent in the model who is 12 years old, has four household contacts and 38 daily school contacts would represent 40 such children across 40 different five-person households in the actual population. We create households by assigning agents to households using data on the distributions of household sizes.[22] Next, we assign children (aged 6-18) to schools, using data on classroom sizes of (37.55 students/class) and gross school attendance rates (85.6% for children of primary school age, 70.8% for children of secondary school age). To assign adults to workplaces, we note that although the average firm in Nigeria employs 300 people,[23] there is significant variation around this depending on the type of business, unemployment of 25-30%, and little data for inform estimates of contact rates for those in the informal economy. It is also unlikely that people employed at larger firms would have contact with all employees on a given day. Consequently, we model the number of workplace contacts using a Poisson distribution, with each working age adult in the population having a mean of 20 daily contacts. Finally, we assume that in addition to their work and school contact networks, each person in the model may have contact with other members of the community. The number of community contacts that each person has varies daily, and is drawn from a Poisson distribution with a mean of 20 daily contacts.

Disease progression and transmission

We model disease dynamics using Covasim, a stochastic agent-based model of COVID-19.[24] Each individual is characterized as either susceptible, exposed, recovered, or dead, with exposed individuals additionally categorized according to whether or not viral shedding has begun, and according to their symptoms (asymptomatic, mild, severe, or critical). Covasim's parameters determine the ways in which people progress through these states, including the probabilities associated with onward transmission and disease progression, duration of disease by acuity, and the effects of interventions. The baseline parameter values were collated during Covasim's development and summarize the evidence available up until June 30, 2020.[25]

To calibrate Covasim to the epidemic in Lagos, we gathered data on the number of confirmed cases and deaths from March 1, 2020, to June 30, 2020, as reported by the Nigerian CDC. The per-contact probability of viral transmission (β) varies with the nature of contacts - for example, maintaining physical distancing could decrease the probability of transmission per contact. There is also considerable uncertainty about whether this probability is affected by temperature,[26] dependent on age,[27, 28] or is lower for asymptomatic cases.[29, 30] To reflect this, we conduct sensitivity analyses around the value of β, including a median scenario in which the average attack rate would lead to an R_0 of 2.5 in the absence of interventions, and high/low scenarios corresponding to R_0 ranging from 1.5 to 3.5, consistent with the range used in other modelling studies and reported from early outbreak analyses.[31] We present a range for each of our results corresponding to this range in R_0 values.

Effects of mitigation policies

Lagos lockdown from March 30 to May 3: We model the effect of the lockdown by assuming that the transmission risk associated with workplace-related contacts was halved during the lockdown (reflecting stay-at-home orders). We also reflect school closures by removing transmission over school networks. Other aspects of lockdowns (including the closure of restaurants, gyms and sports clubs, and places of worship, and the increased prevalence of hand-washing and masks) are approximated by reducing the transmission risk associated with community contacts by 50%, in line with movement reductions reported by Google over this period.[32]

Phased release of lockdown from May 4: After the release of the lockdown, we assume that work and community activities resume, but with reduced transmission risk (80% of pre-lockdown levels) owing to the additional non-pharmaceutical interventions in place (face masks, handwashing, physical distancing restrictions, and the 10pm–4am curfew). Other measures, including the closure of state borders, closure of schools, and bans on public gatherings, remain in place.

Testing, tracing and quarantine: According to the Nigerian CDC, just over 35,000 tests had been conducted in Lagos by June 30, 2020[33]. From May 4, we assume that those with severe symptoms (using the clinical classification provided in Wu et al [34]), as well as those known to have had contact with confirmed cases, are instructed to self-quarantine either at home or in shelters,[35] even before they have received a confirmed diagnosis. Quarantine is assumed to reduce a person's workplace contacts to zero, reduce their community contacts by 95%, and to have no effect on their household contacts. These estimates of the effect of quarantined on workplace and community contacts are likely to be extremely optimistic based on estimates of adherence from other contexts,[36] but we model this in order to understand the best-case scenarios that could be hoped for under quarantine. Contact tracing is carried out for each confirmed case and we assume it can successfully locate 100% of household contacts within a day, and 80% of workplace contacts within 1 week.

To supplement the limited number of tests available, we investigate the use of symptom-based screening, as included in the Nigerian's CDC's response plan, as a way to increase the number of people with COVID-19 who are quarantined without increasing demand for tests. We run two arms of scenarios representing alternative policies regarding those with mild symptoms, as shown in Figure 1 and Table 1.

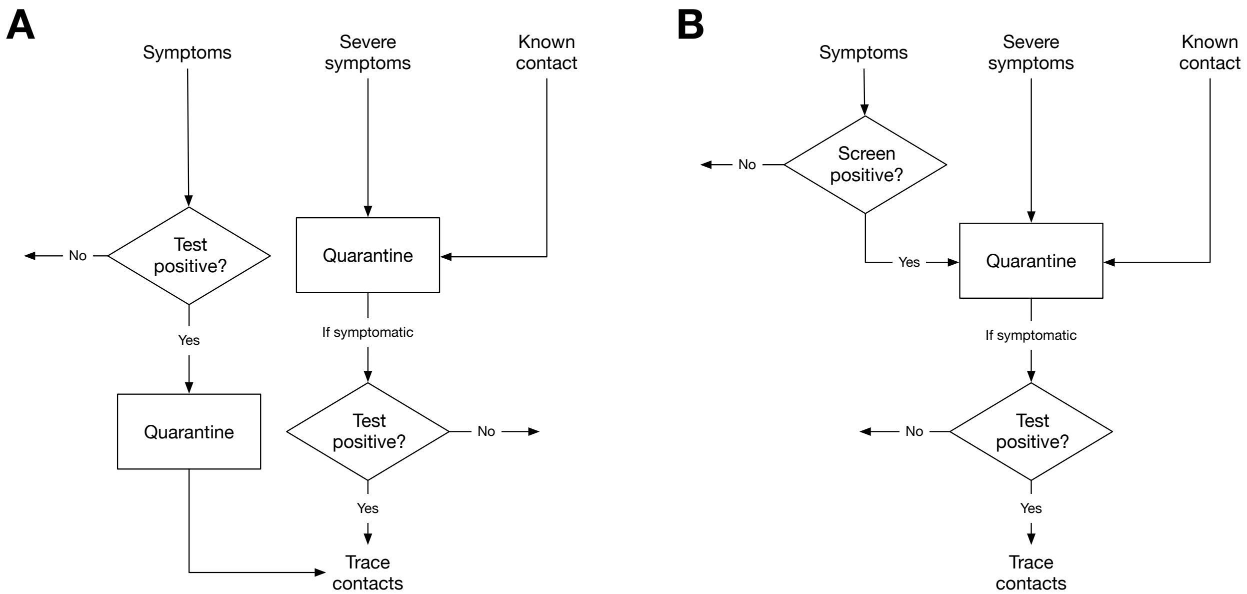

Figure 1. Overview of quarantine and testing scenarios a) without fever screening, and b) with fever screening.

	Scenario 1: no screening	**Scenario 2: with fever screening**
Screening policy	• No screening	• 10–50% of adults screened for fever daily, representing a range of scenarios about how much of the population could be screened • 10–50% sensitivity of fever screening for COVID-19 diagnosis, using a range of estimates corresponding reports about the % of all infections with fever.[2]
Testing policy	• Eligible for testing if symptomatic • Tests prioritized according to case severity/contact history (those with severe symptoms are 10x more likely to get tested than those with mild symptoms; those with known case history are 10x	• Eligible for testing if required to quarantine and symptomatic • Tests prioritized according to case severity/contact history (those with severe symptoms are 10x more likely to get tested than those with mild symptoms; those

	more likely to get tested than those without).	with known case history are 10x more likely to get tested than those without).
Quarantine policy	Quarantine individuals with • confirmed diagnosis, or • severe symptoms (even without a confirmed diagnosis), or • contact history (even without confirmed diagnosis)	Quarantine individuals with • confirmed diagnosis, or • severe symptoms (even without confirmed diagnosis) , or • contact history (even without confirmed diagnosis) , or • fever

Table 1: Summary of the two scenarios examined in this study with differing policies for screening, testing, and quarantine.

Epidemic model analysis

Firstly, we initialize the model on March 1, 2020 by seeding a single case, and we run the model on a population representative of Nigeria until June 30, 2020. We include the testing that was conducted over this period as well as the effects of the lockdown, and we compare the model estimates to the data available on the number of confirmed cases and deaths for Nigeria. We use this to estimate the number of active cases in the population as of June 30 with and without the April lockdown. Next, we run the model for an additional 180 days starting from July 1, 2020 assuming that new policies (as described in the previous sections) came into effect from May 4, 2020. We calculate the numbers of cases by symptom severity (asymptomatic/mild/severe/critical), the number of diagnoses and tests, and the number of deaths and recoveries on a daily basis under the two scenarios discussed above, i.e. with and without fever screening. For the scenarios with fever screening, we tested a range of assumptions about the efficacy of fever screening and the proportion of the population that could be screened, as summarized in Table 1.

Results

We estimate that there were approximately 90,000 [80% forecast interval: 35,200–120,100] people infected with COVID-19 in Lagos State on June 30, 2020 (Figure 2a), with approximately 1/9 of these having been diagnosed. In the absence of the lockdown, we estimate that the number of infections would have been far greater, with approximately one quarter of the population of Lagos having been infected by the end of June 2020 (Figure 2b), and 40 times as many deaths.

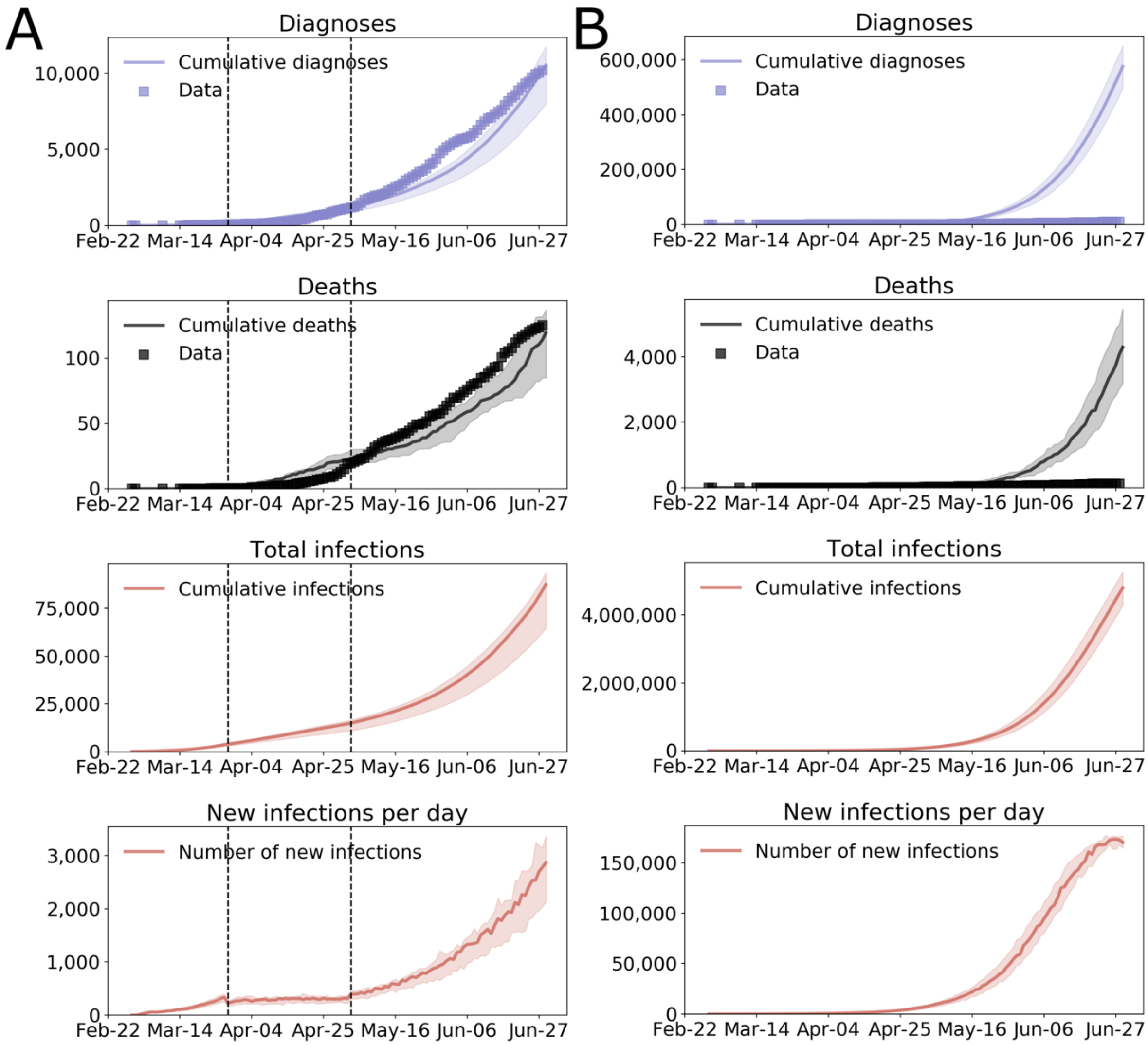

Figure 2. Epidemic estimates for Lagos State over the first 65 days of the epidemic (a) with lockdown in effect from March 30-May 4; (b) without lockdown. The model calibration assumes accurate reporting of deaths. The dotted line indicates the beginning of the Lagos State lockdown.

Over the second half of 2020, we find that screening could play a role in containing symptomatic cases of COVID-19, especially if testing capacity is limited. We estimate 4.75 million cases of COVID-19 in Lagos State by the end of December 2020 without symptom screening. If fever screening were conducted throughout the year and people with fever instructed to self-quarantine, we estimate that this would avert between 2–86% of infections that would occur over the six months from July 1–December 31 in the absence of fever screening, with the range depending on the sensitivity of screening and the proportion that could be screened (Figure 3). We estimate that the number of people placed in quarantine over the course of the month would be 2–80% higher if fever-based quarantine measures were in place but would improve the yield of testing by 1–87%, reflecting the fact that tests would be better targeted.

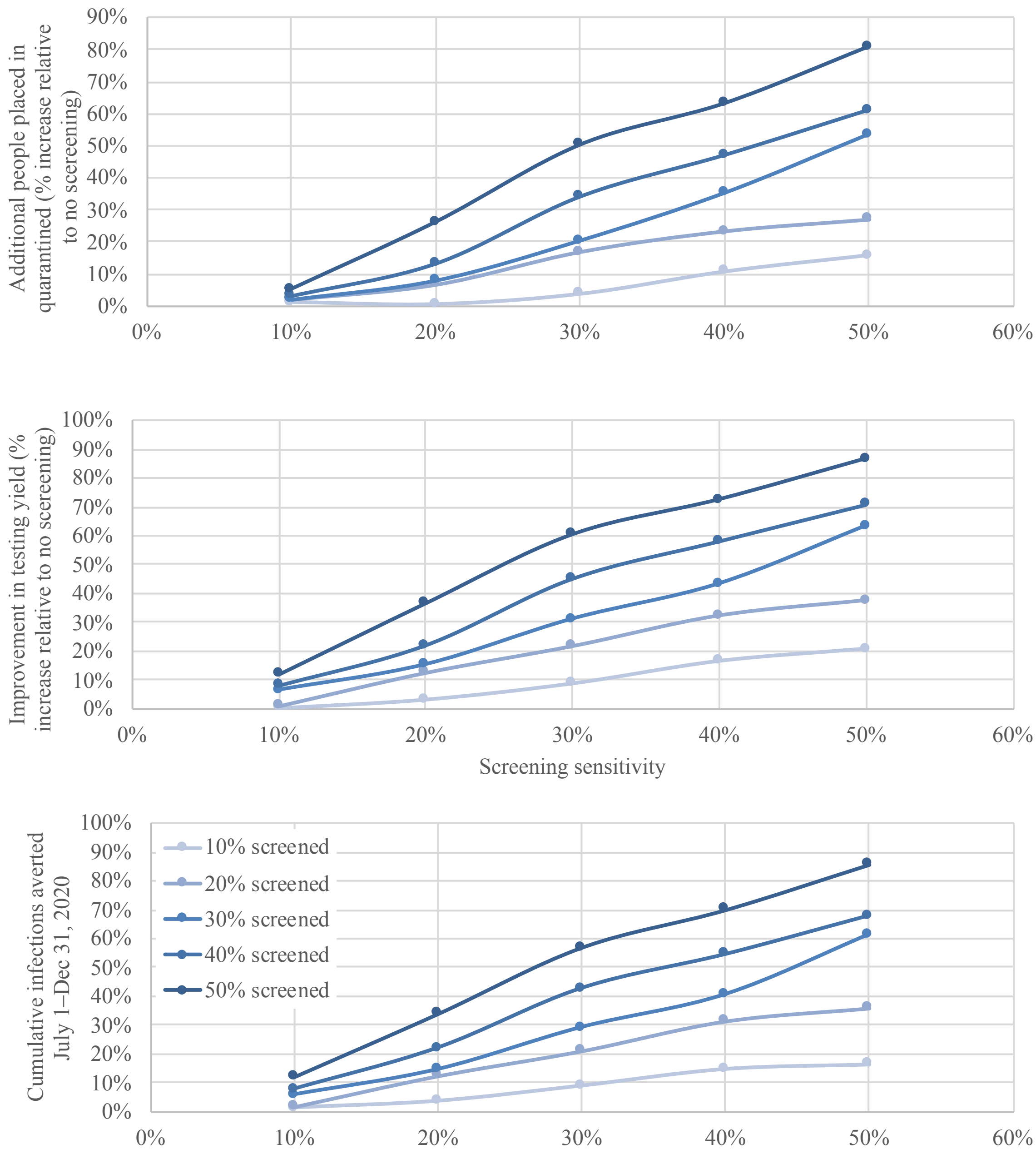

Figure 3. Epidemic estimates for Lagos State under different assumptions with and without supplementary symptom screening.

Discussion

We estimated the development of the COVID-19 epidemic in Lagos State during different phases of the epidemic: the initial growth phase over March 2020 as new infections spread throughout the city, the five weeks of citywide lockdown from March 30, 2020, and the subsequent phasing out of lockdown, accompanied by test-trace-quarantine or screen-quarantine-test-trace based containment measures. We found that successful control of the epidemic is unlikely to be practical with COVID-19 tests alone as more tests per day are required than is realistically possible. Fever screening could both increase test yield and reduce the extent of the spread, both by adding to the number of possible cases that are quarantined and by making contact tracing more effective, but would not be sufficient to control the epidemic.

Several other studies have examined test-and-trace-based containment strategies of COVID-19 in different contexts. Modelling studies have provided evidence that the success of such strategies depends largely on the proportion of symptomatic cases [37] as well as the speed and success with which contacts can be traced.[31, 38, 39]. The cost of such strategies is also an important consideration: not only the cost of testing kits, but also the costs associated with contact tracing.[40, 41] In our model of Lagos State, we used age-linked probabilities of developing symptoms, with younger people less likely to develop symptoms than older people. In a population like the UK, these age-linked probabilities translate to ~70% of the population being symptomatic, but in Nigeria, where half the population are under 18, they translate to a symptomatic proportion of only 48%, which would in turn limit the potential for test-based containment strategies.

This study has numerous limitations stemming from the degree of uncertainty around the state of the epidemic in Lagos State and Nigeria more broadly, and the parameters that govern transmission. Where possible, we have tried to account for this uncertainty by incorporating sensitivity analyses around key parameters (such as the transmission rate). However, the rapidity with which the COVID-19 situation evolves makes it impossible to meaningfully quantify all sources of uncertainty. In particular, policy is made dynamically and responsively to epidemic changes, and it is unlikely that the epidemic would reach the scale shown in these projections without additional measures, possibly including a second phase of lockdown, being put into place. The Nigerian government has advocated the use of additional measures to mitigate COVID-19 spread, including the mandating of face masks and night-time curfews. Evidence on the efficacy of face masks in preventing the transmission of SARS-CoV-2 is mixed, especially for non-surgical cloth masks,[42, 43] which are likely to be the most common form used in Nigeria given supply-side constraints on mass manufacturing of medical-grade masks. We did not model the effect of face masks in this work, but plan to incorporate these in future work.

Testing will play an important role in guiding the choice of interventions after the lockdown is lifted to prevent a second wave of infections. Targeting tests towards those most likely to be positive cases, whilst simultaneously instructing unconfirmed cases to isolate where possible, may go some way towards reducing transmission while tests remain in limited supply. However, it will not be as effective as increasing testing capacity; ultimately, more tests will be needed for Lagos State to contain the epidemic if another lockdown is to be avoided.

Contributorship

RMS, RA, and CK wrote the manuscript, calibrated the model, and produced the results. ALO reviewed the data. CK, RMS, RA, DM, and DJK led development of the model (along with numerous other contributors listed below).

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Competing interests

We declare no competing interests.

Data sharing

No additional data.

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