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Original article

COVID-19 in a Nigerian university: Modelling the spread of SARS-CoV-2 on an average university campus

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ABSTRACT

Background: Currently, the world is overwhelmed with coronavirus disease 2019 (COVID-19) caused by a highly virulent virus that causes influenza-like symptoms. University administrators are confronted with challenges concerning coronavirus preparedness and response for the resumption of safe campus activities. This study aimed at assisting Nigerian Universities in COVID-19 preparation and response. **Methods:** We adopted the susceptible-exposed infectious-recovered (SEIR) deterministic model to appraise the transmission of SARS-CoV-2 among university staff and students and evaluated the breadth of non-pharmaceutical intervention strategies required to safely return its community to campus. The mode was parameterized to fit the resident on campus situation. The frequencies of viral screening and testing, probabilistic sensitivity analysis of model parameter was explored in this study. **Results:** Weekly COVID-19 screening reduced the cumulative incidence by 15% and 55.7% among university staff and students, respectively. Polymerase chain reaction (PCR) testing delay of 2-,3-,4-and 7 days reduced overall semester incidence by 65.7%, 56.9%, 50.8% and 34.4% among students; 23.5%, 22.8%, 20.5% and 16.9% among university staff. **Conclusions:** Our simulations have revealed that extensive testing of on-campus community population may be required to curb disease explosion. While cases of hospitalization and deaths may occur, community import of COVID-19 can be curtailed with effective testing, isolation, contact tracing and quarantine. A cost-effective solution such as pool testing was proposed in this study to decrease the overall resources needed for comprehensive on-campus testing.

Introduction

Endless outbreaks of infectious disease pandemic have shaped the history of mankind and studies have warned us that a new influenza-like pandemic was on its way[1, 2]. Currently, the world is overwhelmed with coronavirus disease 2019 (COVID-19) caused by a highly virulent virus (severe acute respiratory syndrome coronavirus 2 or SARS-CoV-2) that causes influenza-like symptoms [3]. Entire nations have been shutdown to prevent disease explosion for most part of the year 2020.

The Nigerian Federal ministry of health confirmed the first case of COVID-19 in Lagos, Nigeria on 27th February, 2020 [4]. The situation

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spiralled downwards and led to an approval for the closure of all schools on 19th March, 2020 as a non-pharmaceutical intervention (NPI) meant to decrease contact among students, school staffs and family members by extension [5]. Because young people are vital in the spread of respiratory viruses [6], school closure was assumed to be an effective practise of reducing disease transmission [5]. This measure affected about 46 million students countrywide, especially in the North and Bay areas where the educational system was already stretched [7].

Severe acute respiratory syndrome coronavirus 2 infections are chiefly severe among older adults despite the that fact younger people still contract the infection and transmits it [8]. The university community is normally residential and unique in terms of mixing across different age groups (old and young) [9]. It involves students travelling across state boundaries to attend [9].

On 18th September 2020 the Federal Government-approved national universities commissions (NUC) directives for the safe reopening of universities during the pandemic was broadcasted [10]. Consequently, university administrators are now faced with challenges concerning if and how to securely return students and staff to campus. Universities need to approximate the essential resources to interrupt and curtail campus transmission by analysing the number of likely cases, screening requirements and testing (antigenic, PCR or both), and setting up isolation dorms for people requiring isolation and quarantine.

To provide a framework to evaluate these questions, we utilized a susceptible-exposed infectious-recovered (SEIR) method of deterministic compartmental model that appraise the transmission processes. The model can estimate direct and indirect effects of intervention strategies. This paper is aimed to support pandemic planning in Nigerian universities by making case projections that will aid in averting transmission chains that would have otherwise occurred as schools resume.

Methods

We modelled transmission of SARS-CoV-2 among university staffs and students of an average Nigerian University. We describe the key features and assumptions in the following sections.

Population and Transmission

We modelled three discrete groups with diverse interactions; University staff and students living on- and off-campuses. The model compartments for SARS-CoV-2 transmission is shown in **figure (1)**.

Model Assumptions

1. Before non-pharmaceutical interventions we assume that university staffs can be infected by students and in turn infect other staff members, with a reproduction number of 0.5.
2. Viral transmission between student-to-student association occurs at a higher rate (R0=2) before interventions.
3. Transmission potential is higher among students living on-campus than off-campus students, because overcrowded hostel accommodation is characteristic of most Nigerian campuses.
4. Boarding students infect an average of one student on campus.

To limit on-campus spread of the virus, most university administrator have planned or are setting protocols to check its trajectory. On-campus protocols like hand washing; face coverings (shields and/or masks); use of other PPE's; phased resumption; reduce class sizes; staggered class times; improved hygiene and sanitation; discouraging large gatherings.

In our target population, data on the usefulness of non-pharmaceutical interventions are scarce. But anecdotally, we suppose that they may affect viral transmission rate.

A large proportion of cases occur asymptomatically, and symptomatic cases are likely among university staffs than students. Further, university staff are at a higher risk of illness/death from the virus than students, based on reported age-differences in the death rate [11] . We assume physical distancing and face covering compliance is about 50%. Symptomatic and asymptomatic (pre-symptomatic) cases are harmoniously infectious (An assumption that could overemphasize actual transmission rate [12]. The duration of incubation of the virus is longer than the latent period and a carrier will become infectious on the third day post infection. We only track introduction of virus onto campus from the surrounding community. To capture this, we modelled a constant daily rate of infection being introduced on campus. This is based on confirmed COVID-19 cases in Nigeria of about 100 cases per day as at the time of this report (September 2020) [13]. We also assume that incidence of infection is 10

times that of documented cases [14]. We ran the model for a semester (120 days).

Intervention Design

Control of SARS-CoV-2 is initiated by diagnostics. Infected persons can be identified by reverse transcription polymerase chain reaction (RT-PCR) through either testing or screening, defined as follows;

- Testing is a strategy whereby symptomatic staff and students are tested using real time RT-PCR (rRT-PCR). [15]. Polymerase chain reaction positive participants are immediately isolated. PCR sensitivity is not 100% and varies based on what stage of the illness the test is carried out [15]. Screening is a strategy in which staff and students are tested at a specified rate (weekly, monthly and once per semester) notwithstanding of the presence of symptoms.

Polymerase chain reaction sensitivity varies over the period of infection [16]; it reaches peak sensitivity around the seventh day of infection or the fourth day of infectiousness after which it gradually declines again [17]. Accordingly, we studied the effect of difference time interval for testing, defined as the average time amid symptom onset and quarantine. We simulated test delays from the most optimistic (2-day) to a least optimistic (7-day) scenario. PCR positive cases are immediately isolated post-testing and their contacts traced. Here isolation and quarantine refer to reduction of contact rate for the period of infection.

Contact tracing is carried out by presuming health task forces are aware of the contacts per case detected with about 75% of those successfully traced and quarantined.

Estimation of parameters and analysis

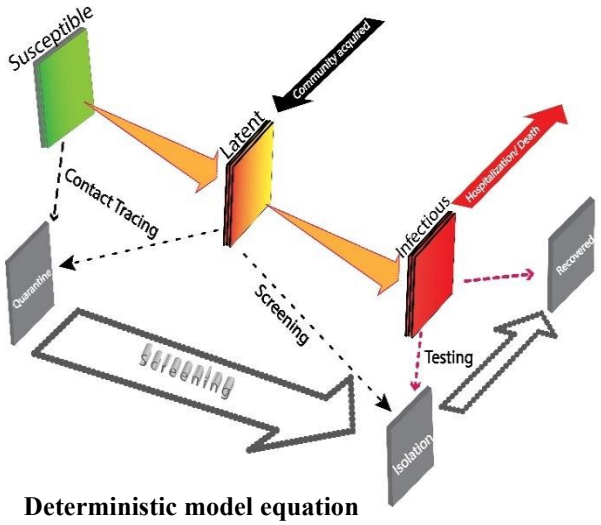
Model exploration was carried out with *Lopmanlabs covid_campus_model* package in R® software (version 4.0.2) [18]: A package that was built and simulated with *EpiModel* package [19]; The package provides functionality for continuous-time deterministic model solved by ordinary differential equations. The sampling algorithm is driven by Latin Hypercube Sampling, accomplished with the *LHS* package [20].

The Basic model employed non-pharmaceutical interventions only (without viral screening or testing). Next, different degree of screening, testing contact tracing were explored. The major outcomes estimated the number of active and cumulative cases, and COVID-related mortality among university staff and students in a semester.

The parameters on the total number of students and the number of staff on campus were estimated based on data obtained from the National universities commission [1, 21]. An elaborated data description is given in **table (S1)**.

The model was ran based on the assumption that average population of campus student and staff was 10033 and 5364 respectively. Based on the assumption that the total number of students living off and on campus remain fixed at 75% and 25% respectively according to reference [21], we have 7525 students living off-campus and 2508 living on-campus.

Figure 1. Schema of the compartment model of SARS-CoV-2 disease transmission dynamics



Deterministic model equation

SARS-CoV-2 transmission model is given by the system of differential equation below where; S = susceptible, L= latent, I= infectious, Γ = isolated, Q= Quarantined, R= recovered, ω = Proportion community cases, τ= Testing, ϖ = PCR sensitivity, ε = proportion of asymptomatic population, θ = contacts traced, R0 = Viral Reproduction rate, χ = Latent period, κ = infection rate, ς = screening, ϕ= duration of quarantine, β = isolated proportion , ρ = proportion of contacts traced.

$$\dot{S} = -\lambda S_i - \omega S_i - \tau\varpi(1-\varepsilon_i)I_i(\theta - R_{0_i})\rho\theta + \frac{i}{\beta}Q_i(\theta - \frac{R_{0_i}}{\theta}) \quad (0.1)$$

$$\dot{L} = \lambda S_i + \omega S_i - \chi L - \varsigma\varpi L - \tau\varpi(1-\varepsilon_i)I_i R_{0_i} \quad (0.2)$$

$$\dot{I} = \chi L - \kappa I_i - \varsigma\varpi I_t - \tau\varpi(1-\varepsilon_i)I_i \quad (0.3)$$

$$\dot{\Gamma} = \tau\varpi(1-\xi) + \varsigma\varpi(L+I_i) - \Gamma\phi \quad (0.4)$$

$$\dot{Q} = \tau\varpi(1-\xi)I_i(\theta\rho_\theta) - \phi Q \quad (0.5)$$

$$\dot{R} = \kappa I_i + \phi L + \phi Q\frac{R_{0_i}}{\theta} \quad (0.6)$$

Where λ for on campus (α), off-campus (δ) and University Staff (z) is defined as follow;

$$\lambda_\alpha = (1-eff_{xpi})(\sigma_{ss}(I_\alpha + I_\delta) + \sigma_{\alpha\alpha}I_\alpha + \sigma_z I_z) \quad (0.7)$$

$$\lambda_\delta = (1-eff_{xpi})(\sigma_{ss}(I_\alpha + I_\delta) + \sigma_{\alpha\alpha}I_\alpha) \quad (0.8)$$

$$\lambda_z = (1-eff_{xpi})(\sigma_z(I_\alpha + I_\delta + I_z)) \quad (0.9)$$

Table 1. Model parameters

Parameter descriptions	**Starting value**	**Reference**
Total students	10,033	[22, 23]
Students living on Campus	2508	[21, 23]
Students living off Campus	7525	[21, 23]
Academic and non-academic staffs	5364	[24]
Latent period (days)	3	[25]
Infectious period (days)	7	[4]
Proportion severe - students	0.0326	[26]
Proportion severe - staff	0.0566	[26]
Proportion fatal - students	0.0004	[26]
Proportion fatal - staff	0.0073	[26]
Proportion symptomatic - students	0.39	[27]
Proportion symptomatic - staff	0.48	[27]
R0: students to students	2	Fitted
R0: on campus students to other on campus students	1	Fitted
R0: Staff to student; staff to staff	0.6	Fitted
Daily new cases in community (proportion)	0.0018	WHO
Under-reporting factor for community infections	30	[4]
Efficacy of face-coverings and social distancing	0.8	[28]
Time from onset of infectiousness to testing (1/days)	3	Fitted
Screening frequency (1/days)	30	Fitted
Duration of quarantine [days)	14	[29]
Number of contacts per case	4	[30]
Proportion of contacts reached	0.15	[31]
Proportion experiencing symptoms per day	0.003152	[32]
PCR sensitivity -- day 2 of infectiousness	0.68	[17]
PCR sensitivity -- day 4 of infectiousness	0.75	[33]
PCR sensitivity -- day 7 of infectiousness	0.77	[33]

Results

First, we simulated on campus transmission without diagnostic control measures like testing, contact tracing, isolation and quarantine. At R0 of 3 and 2 for on-campus off-campus students, case prevalence peaked at 565 cases (Range, 2.5th to 97.5th centiles: 383 to 813) per day among students and 51 cases per day among university staff (28 - 79), leading to a cumulative of 2,050 (1,432 - 2,607) and 365 (188 - 570) cases at the end of the semester in a population of about 15397. With baseline value of facemask and social distancing efficacy (80%) with no diagnostics, case prevalence peaked at 141 (36 - 639) daily among students and 26 (10 - 58) cases daily among university staff, resulting in a cumulative student cases of 887 (234 - 2,308) and 259 (103 - 444) cases among university staffs at the end of the semester **(Figure 2)**.

Then we simulate different screening intervals, from weekly to once in a semester **(Figure 3)**. One-time screening, whereby the population is tested on average once during the 120 days long semester, reduced cumulative student incidence by 5.6%; monthly and weekly screening intervals reduced cumulative student incidence by 28.5% and 55.7% respectively. For staff and faculty, one-time screening reduced cumulative incidence by 4.8%; monthly and weekly screening reduced cumulative incidence by 12.7% and 15% respectively. For students, the cumulative incidence varied from 341 (148 - 639) with weekly screening to 689 (175 - 1,917) with one-time screening. For university staffs, the cumulative incidence ranged from 197 (102 - 342) with weekly screening to 237 (113 - 408) with one-time screening.

Furthermore, we explored a testing-only strategy, which also take account of contact tracing and quarantine. Considering different lag time between symptom-onset and testing, results are illustrated in **figure (4)**. We again plot the cumulative number of cases among students and staff, with other parameter values at their base values. Here, with one week-delayed testing (the least optimistic scenario), the expected cumulative incidence was 591 (294 - 939) for students and 215 (94 - 387) for university staff. With a four-day test delay, the expected total incidence would be 443 (155 - 679) for students and 206 (92 - 355) for staffs. With a Three-day delay testing interval, the anticipated cumulative incidence would be 388 (182 - 649) for students and 200 (92 - 369) for staff/faculty. With a two-day delay testing interval, the expected cumulative incidence would be 309 (142 -552) for students and 195 (84 - 351) for staffs. These scenarios represent a 34.4%, 50.8%, 56.9% and 65.7% reduction in cumulative incidence at the end of the semester among students and 16.9%, 20.5%, 22.8% and 23.5% reduction in cumulative incidence among staffs. Figure 4 also illustrates the association between successful contact tracing and cumulative incidence assuming either a 2-day, 3-day,4-day, or 7-day testing/quarantine delay after symptom onset. Even though the testing interval may reduce the cumulative incidence, the greater effect of traced. This scenario is reached by the number of contacts.

Finally, we combined the testing and screening frequencies under multiple assumptions of contact tracing related to testing. **Figure 5** shows cumulative incidence at the end of the semester for students only. The scenarios below varied the interval for screening between 7 and 120 days, and testing at 2-, 3- , 4- and 7-day delay, with the efficacy of contact tracing ranging from 0, 25%, 50%, 75% and 100%. Screening generally has little effect when combined with testing unless it is carried out at least once every month.

Figure 2. Effect of non-pharmaceutical interventions (with no testing and screening) on COVID-19 prevalence among students and faculty

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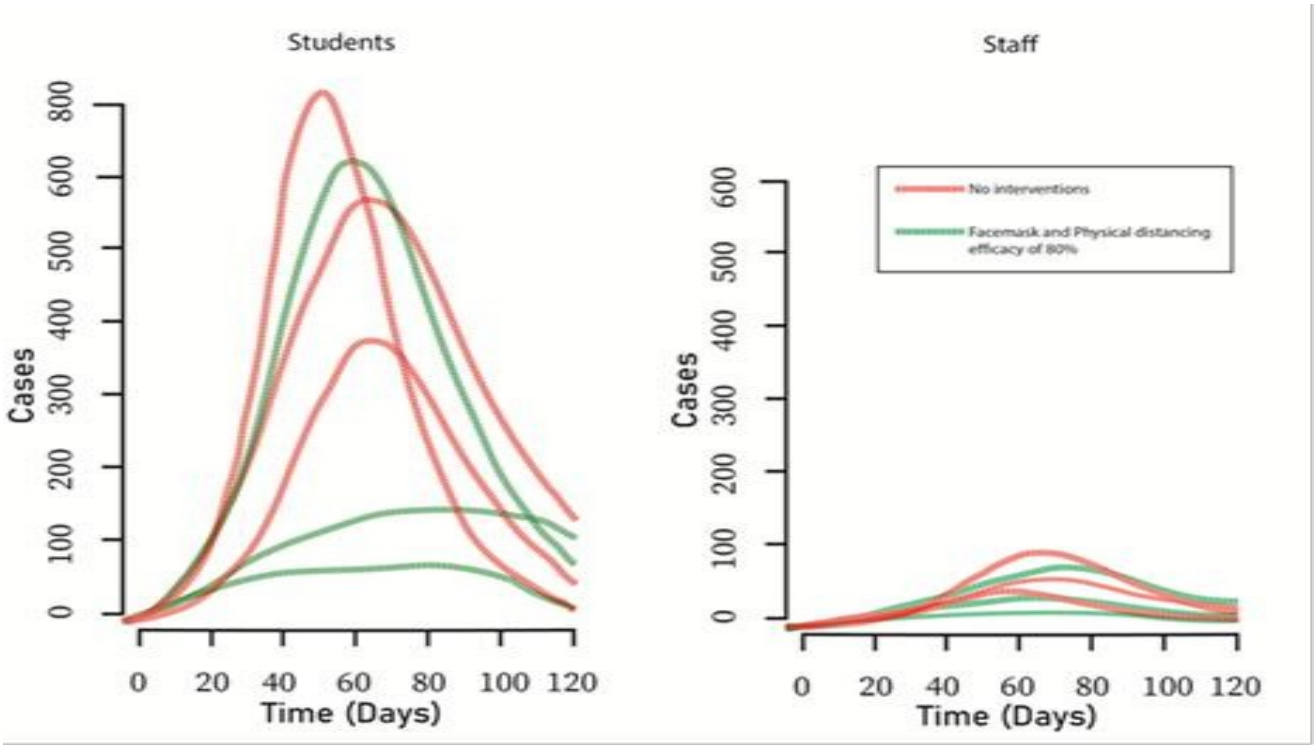

Figure 3. Effect of Screening regularity on projected COVID -19 cumulative incidence.

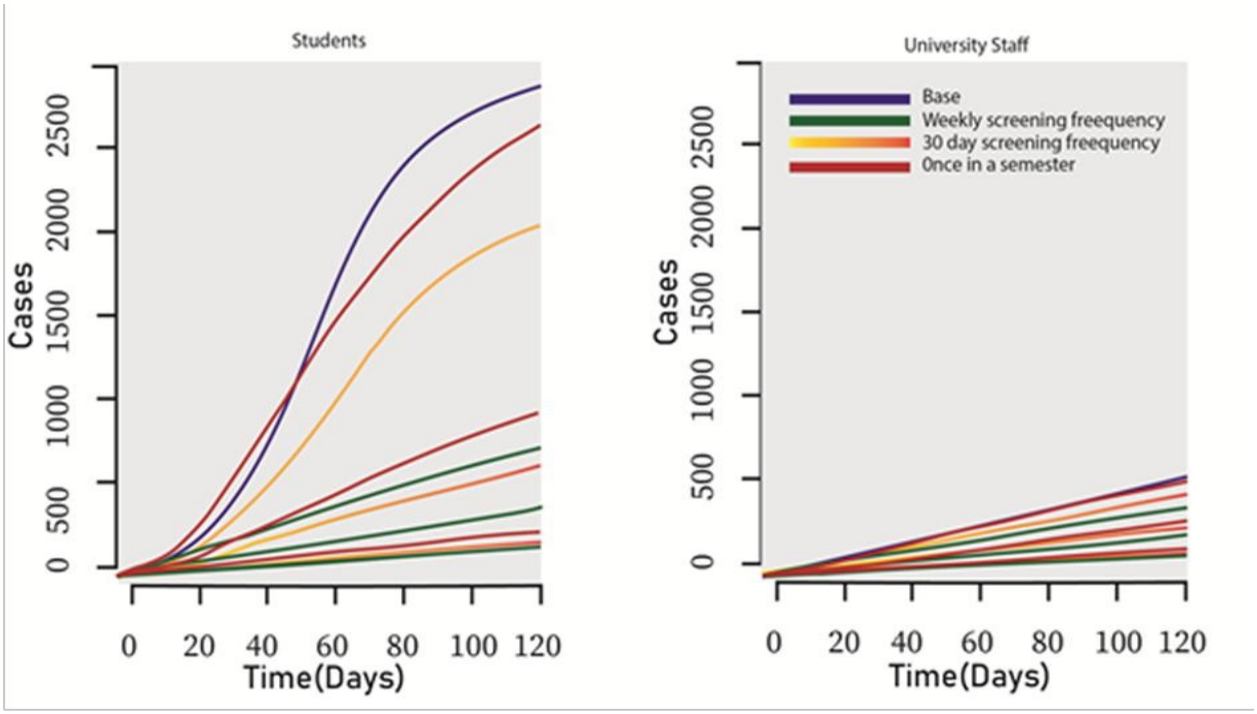

Figure 4. Effect of testing contact tracing and quarantine at a range of testing intervals. Daily and cumulative COVID -19 incidence on campus.

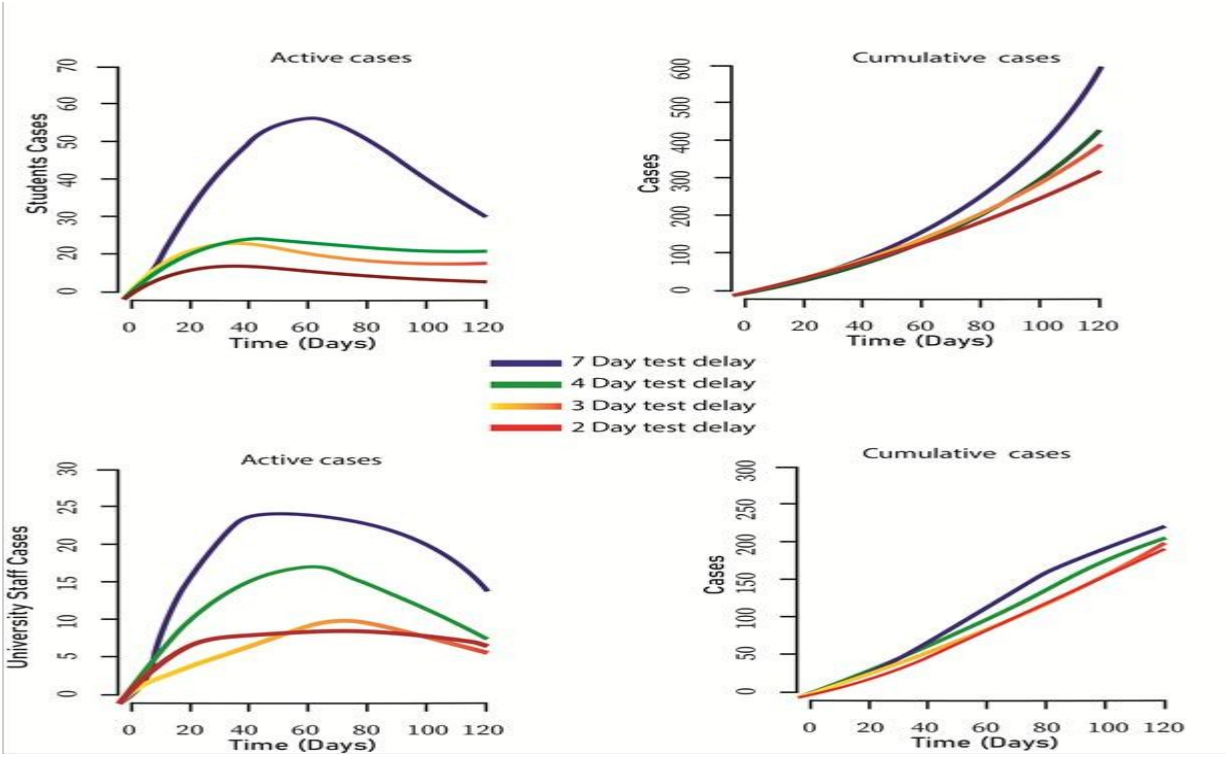

Figure 5. Combined effect of screening and testing of COVID -19 cases among students. Red lines signify weekly and monthly screening.

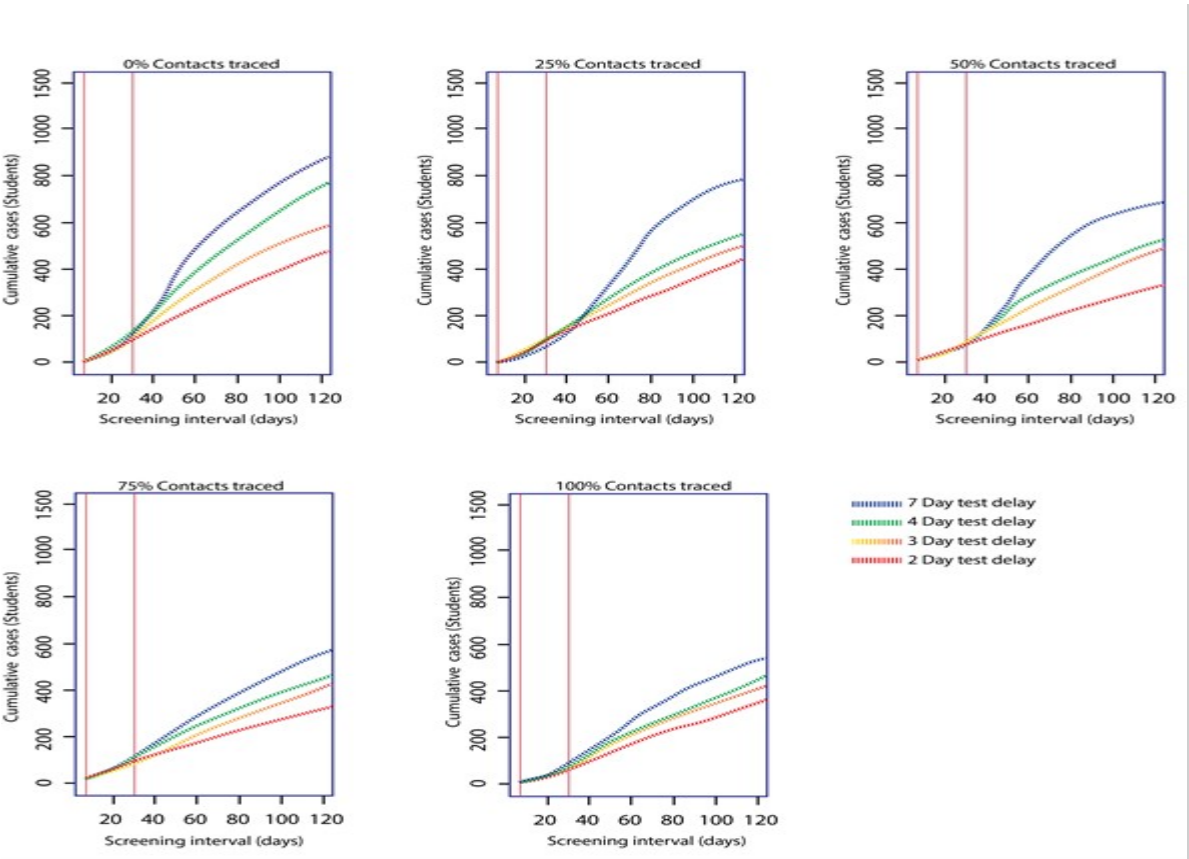

Table 2. Cumulative results at end of the semester on an average sized Nigerian university.

Population	Base scenario	3-day test delay	30-day screen interval	Joint effect of test and screen
Students				
Cumulative Cases (n)	2,501 (1,881 - 3,228)	388 (182 -649)	543 (166 - 1,728)	259 (119 - 485)
Peak Incidence (n)	1,048 (722 - 1,410)	23 (9 - 51)	80 (23 - 350)	7 (3 - 14)
Hospitalizations (n)	141 (74 - 219)	22 (8 - 44)	33 (7 - 99)	14 (5 - 32)
Deaths (n)	4 (2- 7)	1 (0 - 1)	1 (0 - 3)	0 (0 - 1)
Isolated (n)	0 (0-0)	244 (104 -505)	346 (94 - 925)	238 (100 - 446)
Isolated (Peak)	0 (0-0)	30 (13 - 65)	46 (12 - 172)	28 (12 - 54)
Isolated (days)	0 (0-0)	3,040 (1,285 -6,300)	4,207 (1,154 - 11,719)	2,967 (1,241 - 5,555)
Quarantined (n)	0 (0-0)	152 (61 - 319)	0 (0 - 0)	128 (52 - 293)
Quarantined (max)	0 (0-0)	1,218 (489 -2509	0 (0 - 0)	1,072 (439 - 2,429)
Quarantined (days)	0 (0-0)	15,166 (6,044 - 31,279)	0 (0 - 0)	13,336 (5,443 - 30,166)
Staff				
Cumulative cases (n)	456 (294 - 650)	200 (92 - 369)	220 (100 - 382)	186 (89 - 332)
Peak daily cases (n)	97 (60-140)	9 (4 - 18)	22 (10 - 37)	4 (2 - 8)
Hospitalizations (n)	44 (26- 74)	20 (8 - 42)	22 (9 - 48)	18 (8 - 37)
Deaths (n)	5 (2-8)	2 (1 - 5)	2 (1 - 5)	2 (1 - 4)
Testing				
Total performed (n)	0 (0-0)	22,898 (21,704 -24,115)	61,075(61,075 -61,075)	68,636 (67,456 -70,295)
Per capital	0 (0-0)	1 (1 - 2)	4 (4 - 4)	4 (4 - 5)

Discussion

University campuses are not closed communities and even under the most hopeful situation a there is a risk of ingress of the virus into campuses from the community [34]. Because of lack of exact R0 of the disease in our study population, these estimates should be qualitatively interpreted.

Our findings reveal that thousands of illnesses, hospitalizations and possible deaths may occur in an average university campus of about 15397 staffs and students if COVID -19 transmission is not controlled. Such a result is undesirable to university managements.

We documented here that weekly and monthly screening for the virus had considerable influence on its spread on campuses with proportional sampling and testing necessities.

We further project that effective control of on-campus viral transmission could be achieved by prompt identification, viral testing and isolation of symptomatic university staff and student. The success of the aforementioned methods depends on efficient tracing and quarantine of contacts of infected individuals.

Our analysis suffered several limitations which we outline as follows. Firstly, because we assume that there is a constant virus influx from the surrounding community, campus outbreak cannot go extinct. Secondly, our analysis did not overtly include a scenario in which students are screened upon return to campus. Behavioural diversities in use of protective equipment, Phased class times and smaller Class sizes were also not separately accommodated.

Over- and underestimation of risk depends on the surrounding community prevalence and the

activities of university staffs and students off campus. Finally, we did not accommodate epidemiological shifts that may occur as a result of midsemester breaks, seasonal changes and geography.

Recent COVID-19 testing pipeline include nucleic-acid and serological tests. The cost of COVID-19 rRT-PCR test in laboratories in the country ranges between ₦42,000 – ₦51,000 [35]. Our simulations have revealed that extensive testing of on-campus community may be required to curb disease explosion. However, pre-symptomatic individuals may result in large number of PCR negative test thereby increasing the demand for testing supplies. Management of such protocol will be expensive for resource limited institutions. Consequently, we recommend a relatively simple and cost-effective approach like pool testing where samples are combined and tested and positive pools are re-tested separately [36]. This may reduce the total resources required.

Conclusion

Because of continuous mutations, time lag between vaccine prototype development and distribution, it is not at all unfathomable that the virus may likely re-emerge multiple times (multiple waves). We therefore modelled the transmission and control of SARS-CoV-2 to assist university management in forecasting possible effects and resource requirements of the outbreak. We assume that non-pharmaceutical interventions do not reduce the reproductive number. When employed correctly, testing, isolation, tracing and quarantine are prolific strategies for viral transmission control of community imports of SARS-CoV-2 infection onto university campuses.

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Supplementary material

Table S1. Distribution of students in Nigerian universities as at 2012/2013 as obtained from NUC websi

Sector	Number	Student population
State universities	38	438641
Private universities	50	74257
Federal universities	39	761,363
National total	127	1,274,261
Average		**10,033**

Figure S1. Screen snippets of projected model output for active (symptomatic and infectious) and cumulative cases (infectious) under 80% facemask efficacy intervention scenarios.

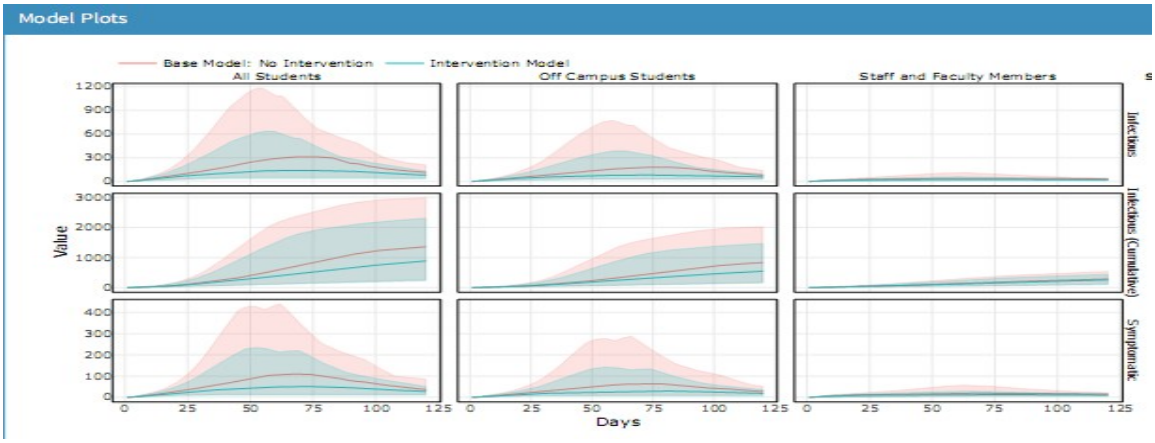


Figure S2. Screen snippets of projected model output for active (symptomatic and infectious) and cumulative cases (infectious) under combined contact tracing and testing delay intervention scenarios.

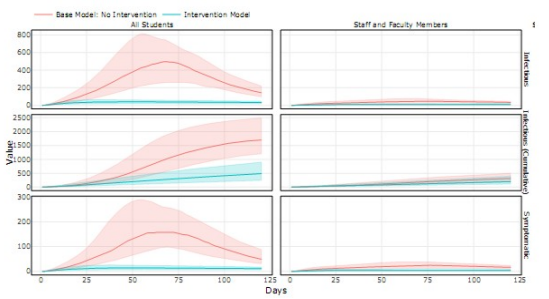
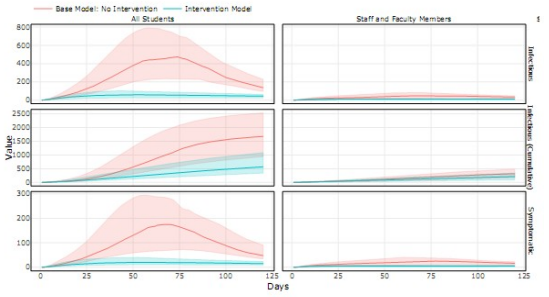
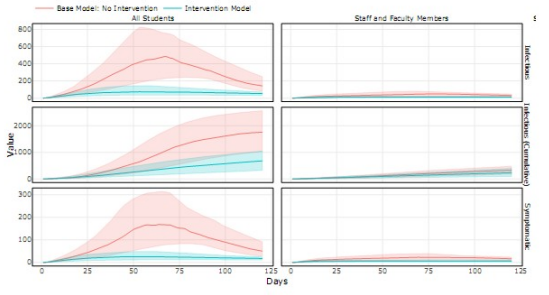
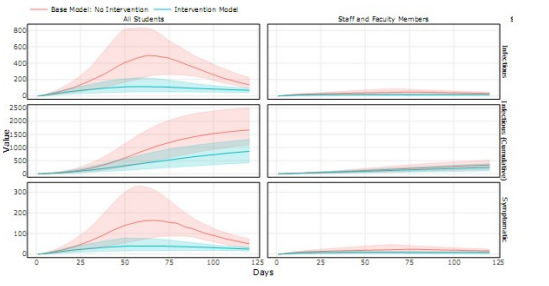
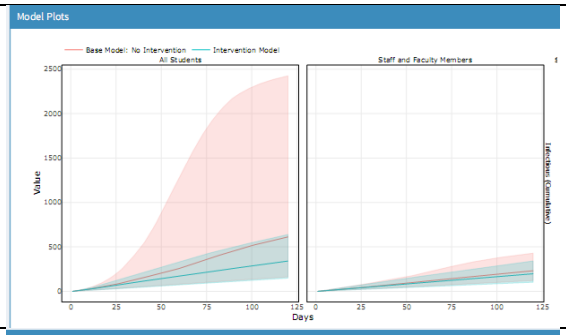
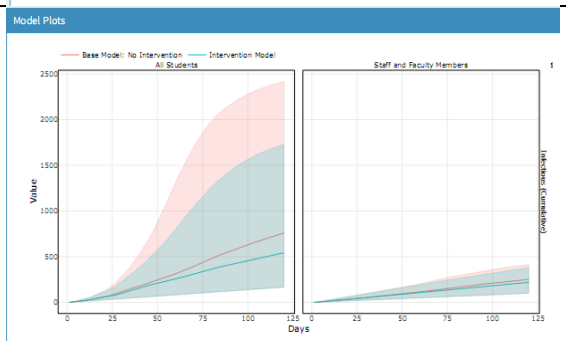
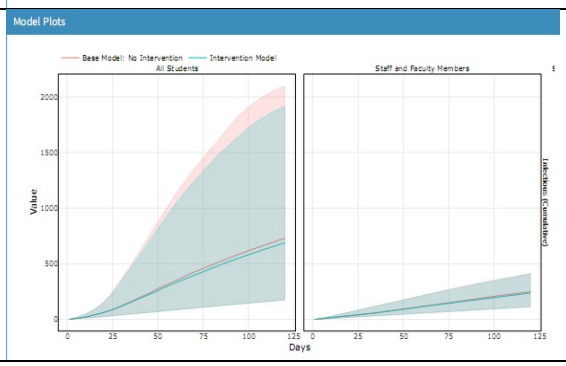
Contact tracing 0% with 2day test delay	
0% contact tracing with 3-days test delay	
0% contact tracing with 4-day test delay	
0% contact tracing with 7-day test delay	

Figure S3. Screen snippets of projected model output for cumulative cases (infectious) screening intervention scenarios.

7-days screening interval	
30-days screening interval	
120-day screening interval	

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