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Impact of contact tracing, respect of isolation and lockdown in reducing the number of cases infected with COVID-19:

Case study: Tunisia’s response from March 22 to 04 May 2020

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Highlights

- As of June 27, 2020, Tunisia had reported 1169 COVID-19 cases with 50 deaths.
- Earlier effective contact tracing implemented, higher reduction in new infections.
- High and early compliance to isolation is two times more efficient in reducing infections.
- Lockdown in Tunisia has had a critical impact the transmission of the virus.
Abstract

Background: COVID-19 has grown rapidly across the world. Tunisia reacted early to COVID-19 resulting in low number of infections. In this paper we model the effects of different interventions on the evolution of cases and compare this to the Tunisian experience.

Methods: We use a stochastic transmission model to quantify the reduction in number of cases of COVID-19 of interventions of contact tracing, compliance with isolation and a general lockdown.

Results: Increasing contact tracing from 20% to 80% after the first 100 cases reduces the cumulative number of infections (CNI) by 52% in one month. Similarly, increased compliance to isolation from 20% to 80% after the first 100 cases reduces the CNI by 45%. These reductions are smaller if the interventions are implemented after 1000 cases. A general lockdown reduces the CNI by 97% after the first 100 cases. Tunisia implemented its general lockdown after 75 cases were confirmed, reduced the cumulative number of infected cases by 86% among the general population.

Conclusions: This study shows that early application of critical interventions contributes to significantly reducing infections and the evolution of COVID-19 in a country. Tunisia’s early success with control of COVID-19 is explained by its quick response.

Keywords: COVID-19, modelling, contact tracing, isolation, general lockdown, Tunisia
Background

Since being recognized in late December 2019, COVID-19 has grown rapidly across the world [1-2]. It has caused huge mortality and morbidity in numerous countries and as of August 10, 2020, 19 718 030 cases of infection and 728 013 deaths have been reported [3]. Almost all countries and territories across the world have COVID-19 cases. However, there are significant differences in the trends and experience of different countries: 10 590 929 cases of infection have been reported in Americas, 3 582 911 in Europe, 1 644 359 cases in the Eastern Mediterranean region, 370 621 cases in the Western Pacific region, 2 632 773 cases in in South Asia and 895 696 cases in Africa [3]. Similarly, there are variations in the case fatality rate, which ranges from 2.6% in Eastern Mediterranean, 1.9% in Africa regions and 6.0% in Europe. At the global level, the rate is 3.7% [3].

In addition to clinical interventions, non-pharmaceutical interventions (NPIs) that aim to interrupt or reduce transmission are essential to combat COVID-19 [4-6]. Major NPIs recommended at the international level to control COVID-19 have been to give priority to active and exhaustive detection for cases, immediate isolation of COVID-19 patients, carefully monitor contacts as well as mandatory quarantine for all inbound travelers from countries with significant transmission of COVID-19 [7]. Many countries also imposed general lockdowns to limit the increases in cases during critical phases, especially in relation to health system capacity.

Tunisia stands out as an interesting example as a result of its relatively small burden from COVID-19 in the first few months of the global pandemic. Indeed, despite its close connections to Europe, Tunisia was relatively well protected from COVID-19, since its first case was imported from Italy on March 2, 2020. The number of cases slowly increased for a while, and a few clusters
of infections eventually emerged [8]. However, large scale community transmission was avoided and until June 27, 2020, the opening date of the borders, only 1169 cases have been confirmed. There have been 50 deaths due to COVID-19 during this period [9].

In this paper, we study the impact of specific NPIs - contact tracing, isolation and lockdown - in reducing the number of COVID-19 cases through applying an existing model. We then adapt this model to take into account specificities of the Tunisian population as well as its epidemiological status. The findings from this paper will help assess different possible control interventions, and mathematical models in relation to real world experience.

**Methods**

Drawing on a methodology proposed by researchers of the Centre for Mathematical Modelling of Infectious Diseases at the London School of Hygiene and Tropical Medicine, we use a stochastic transmission model based on a branching process or Bienaymé-Galton-Watson process to quantify the impact of contact tracing, compliance with isolation and lockdown in reducing the number of cases infected with COVID-19 [10]. Under ideal circumstances due to effective isolation after the appearance of symptoms and full contact tracing, there would be no secondary infections.

In this model, the number of potential secondary cases produced by each individual is drawn from a negative binomial distribution branching process. We estimated the level of overdispersion in COVID-19 transmission by using a mathematical model that is characterized by R0 and the overdispersion parameter k of a negative binomial branching process as described by Hellewell et al (2020) [10].
The simulated process begins with an infected person. After an incubation period, the person shows symptoms and is isolated at a time t. A person infected with the virus could potentially produce secondary infections, with some transmissions occurring before the case is isolated, either due to contact tracing or due to appearance of symptoms. Thus, in the model, a reduced delay between onset and isolation would reduce the average number of secondary cases. The model also takes into account the possibility of asymptomatic transmission (Figure 1).

The possible delays between the onset of symptoms and isolation were based on the later stages of the 2003 SARS epidemic in Singapore and the first phase of the COVID-19 epidemic at Wuhan [11-12]. The incubation period for each case was taken from a Weibull distribution. A corresponding serial interval for each case was then drawn from an asymmetric normal distribution. The other main modelling parameters are a dispersion parameter of 0.16 as used in the original model and a 15% probability of transmission before the onset of symptoms due to emerging evidence in this area [13-14].

Using this model, we assumed varying scenarios according to several parameters, namely the initial number of cases, the reproduction rate (Rt), the percentage of traced contacts, and the efficacy of isolation.

The Rt according to the literature is 4 for scenario 0 without interventions and 0.5 after application of NPIs [15].

Other assumptions about NPIs were made as specified in the paper. For the Rt after isolation, we assume that it is proportional to the percentage of people respecting the NPIs and of the effectiveness of isolation.
We further modify Rt in the community to assess the effect of general lockdown, which is assumed to be 0.5 [16].

1000 simulations are run under each scenario (Table 1).

We then adapt the model to take into account individual characteristics of the population linked to severity of infection. We include the following characteristics relevant to COVID-19: age, hypertension, diabetes, dyslipidemia, chronic obstructive pulmonary disease and smoking. The inclusion of the distribution of the population by age and the prevalence of having at least one chronic disease or smoker in the model is based on the proportion of each group in the general population and the probability of being infected in the observed serial in Tunisia [17,18].

We then re-run the model with Tunisian population data and using the country’s actual number of cases before lockdown and reproduction rate (Figure 2). Once again, we run 1000 simulations with these parameters (Table 2).
The results are presented in terms of relative reduction rates expressed as a percentage, with 95% confidence intervals. For the Tunisian case study, results were calculated for the entire population, by age groups, among those with chronic illnesses and smokers. All the data analysis was performed in the R software.
Results

Model I: Impact of increasing the percentage of contact tracing

The results of Model I show that at a baseline reproduction rate of 4, increasing the identification of contacts from 20% to 80% after the first 100 cases will reduce the number of infections of 40% (95% CI: 37%-42%) after two weeks and 52% (95% CI: 47%-57%) after one month. If 100% of contacts are identified, there will be a 71% (95% CI: 67%-75%) reduction in infections after one month.

However, if the intervention aiming at increasing the percentage of identified contacts is implemented only after the first 1000 cases reported, there will only be a 12% (95% CI: 10%-13%) reduction in infections after two weeks and a 18% (95% CI:16%-19%) reduction after one month as the percentage of contact tracing increases from 20% to 80%.

Figure 1: Impact of increasing the percentage of contact tracing

Initial number of cases=100

Model II: Impact of increasing the level of compliance to isolation

Compliance to isolation has an important impact in reducing infections. The results show that at a baseline reproduction rate of 4, increasing the level of compliance to isolation from 20% to 80% from the first 100 cases will reduce the number of infected cases by 42% (95% CI:31%-52%) after two weeks and 45% (95% CI:29%-61%) after one month. If isolation is respected fully, there will be a 86% (95% CI: 77%-94%) reduction in the number of infections.
If an intervention to increase compliance with isolation is only implemented after the first 1000 infected cases, the reduction rate will be around 28% (95 CI: 26%-30%) after two weeks and 42% (95% CI: 39%-45%) after one month (Figure 4).
Model III: Impact of lockdown

A general lockdown has a positive impact on the reduction of virus transmission with different degrees depending on the time of implementation and the number of cases recorded at that time. A general lockdown will reduce the number of infections by 97% (95% CI:96%-98%) after the first 100 cases, by 93% (95% CI:91%-93%) after the first 1000 cases, and by 82% (95% CI:79%-85%) after 10000 cases.
Tunisian case

Demographics, chronic illnesses and risk factors

Tunisia is a Northern African country in the Maghreb region of North Africa. The population is 11,551,447 inhabitants in 2018, with a quarter aged under 15 and 8% aged 65 years and over. The median age is 32 years. Life expectancy at birth is 75.9 years. There were 68,846 registered deaths in 2018 [17].

In terms of chronic illnesses, 28.7% (95%CI:27.6%-29.8%) of the population suffers from hypertension, 15.5% (95%CI:14.6%-16.3%) from diabetes, 40.9% (95%CI:39.6%-42.2%) from dyslipidemia, and 2.1%(95%CI:1.8%-2.5%) from chronic obstructive pulmonary disease. There is also strong comorbidity among many of these situations. Smoking prevalence is 25.1% (95%CI:23.9%-26.3%). Among people aged 65 and over, 7.7% (95%CI:6.3%-9.1%) suffer from at least one of the diseases listed above and 17.9% (95%CI:15.8%-20.0%) are smokers. In addition, the elderly is particularly vulnerable to Covid-19, especially those with chronic illnesses [18].
The COVID-19 situation in Tunisia (March to June 2020)

Early after to the onset of the epidemic the Tunisian government was committed to complying with WHO recommendations and to its own strategic response and resilience plan for epidemic diseases elaborated on 2018. The Tunisian strategy was based on the 2P2R strategy developed by the NONED and adapted to COVID-19. A Covid-19 Coordination National Committee was appointed and chaired by the Minister of Health. Five early measures were implemented: early cases detection, tracing their contacts, treating those infected at the earliest possible stage, case isolation and treatment. At the same time, authorities were actively engaging the public to participate in social-distancing and other preventive measures. This committee has met regularly since late January. The Tunisian Government also effectively managed the risk associated with cross-border traffic with continuous adaptation and fine-tuning of the measures designed to control of inbound travelers. These have been phased in, broadly corresponding to changing location of the virus outbreak travelers coming from at-risk countries were checked for symptoms upon arrival. In addition, strong contact tracing mechanisms were put in place through the trained regional team in the 24 governorates in February. In early March, the first measures were the suspension of maritime travel between Tunisia and Italy and closure of schools. On March 17, the curfew was decreed and on March 22, a general lockdown was applied until April 4, extended afterwards until May 4 [19].

As of June 27, 2020, the opening date of the borders, the cumulative number of confirmed COVID-19 cases in Tunisia was 1169 cases. Among these cases, 90 (7.7%) are still active, 92.3% of cases having recovered. The case fatality rate is 4.2%, with 50 deaths. 69137 RT PCR tests have
been conducted. The highest number of infected cases is recorded in the region of greater Tunis and in the southern governorates of Kebelli and Medenine (Figure 6) [9].
Modelling results

Impact of lockdown in Tunisia between 22 March and 4 May 2020

To understand the epidemiological results in Tunisia, we adapted the model as described earlier to take into account the demographics, chronic illnesses and smoking behavior of the Tunisian population. We additionally applied the actual number of cases and Rt from Tunisia.

The results of the impact modelling of the general lockdown is consistent with the numbers of infections reported in the country. Indeed, Tunisia implemented its general lockdown after 75 cases were confirmed, on March 22, 2020. In the model, implementation of lockdown at this early stage reduced the number of infected cases by 86% (95% CI: 83%-89%) among the general population, 98% (95% CI: 97%-99%) among people aged less than 24 years, 88% (95% CI: 86%-90%) among people aged 65 years and more, and 92% (95% CI: 90%-94%) among people aged 65 years and more, suffering of chronic illnesses (Table 3). These latter figures are also strongly supported by the low number of COVID-19 deaths in Tunisia.
Discussion and conclusions

The international community is facing an unprecedented global crisis with the fast spread of the COVID-19 pandemic to an ever-growing number of countries and peoples. The epidemic is all the more worrying as there is no vaccine or treatment yet. In order to inform decision making it is important to compare strategies to control the epidemic, reduce mortality and limit pressure on the health system. A major challenge during outbreaks is the design of appropriate control interventions. Mathematical models are increasingly used to guide decision-making and to evaluate interventions. The results of our mathematical modeling have been very informative. They allowed us to conclude that rigorous contact tracing, screening of suspected cases, effective early isolation and a general lockdown have been essential to reduce the number of infections and to control the epidemic.

The results of this modelling clearly show that the earlier effective contact tracing is implemented, the higher the reduction in new infections. The impact of an increase in percentage of contacts identified from 20% to 80% is around three times higher when the intervention is initiated with the first 100 cases compared to a latter intervention with the first 1000 cases. Similarly, higher compliance to isolation after the first 100 reported cases is two times more efficient in terms of reducing infections than if this intervention is implemented after the first 1000 reported cases.

These results are supported by evidence from other countries. Indeed, the impact of contact tracing on COVID-19 has been proven in previous studies [20,21]. Similarly, international evidence shows that isolation of cases and precautionary self-isolation of contacts are key
measures to bend the epidemic curve downwards [22]. They are key WHO recommendations, along with early diagnosis. This combination of interventions has been applied by most countries to control COVID-19 epidemic and prevent a large fraction of possible transmission chains [23].

Furthermore, our model shows that lockdown in Tunisia has had a critical impact on the transmission of the virus. Notably the number of infections among elderly people with chronic diseases has been reduced by over 90% due to lockdown, inducing a limited number of deaths.

This is also supported by the evidence from other countries. Analysis of mortality data in the Chinese province of Hubei suggests that lockdown prevented the deaths of thousands of people [24]. And a more stringent confinement of people in high risk areas seem to have a potential to slow down the spread of COVID-19 [25]. Similarly, France has been heavily affected by the COVID-19 epidemic and went into lockdown on the 17 March 2020. The lockdown resulted in a 77% (95% CI: 76–78) reduction in transmission [26].

Nonetheless, the timing of interventions, including a general lockdown is very critical. The timing of lockdown measures may explain differences in the capacity to contain cases between different countries [27]. For example, Italy implemented a lockdown on March the 11th when it had an incidence rate of 11.71 cases per 10,000 inhabitants and a mortality rate of 0.11 deaths per 10,000 inhabitants [28,29]. In contrast, Tunisia implemented its general lockdown after only 75 reported cases were confirmed (0.65/100 000 habitants), on March 22, 2020.

The population’s compliance to measures imposed by authorities is also critical in determining impact. In Tunisia’s case, with the exception of some lapses, the population largely adhered to the measures put in place by the authorities during the first wave of the epidemic. This is supported by the Rt remaining low in almost all regions of the country and only a slight
increase in the cumulative number of cases from 1025 until the lifting of lockdown on May 4 [16,30].

A strong limitation of this paper is that other effects of lockdown, including the effects on the non-COVID health situation, as mental health, and domestic violence were not included in the model. The huge social and economic impact of lockdown was not studied in this modelling study but have been extensively documented elsewhere [31]. As such the decision to impose general lockdown needs to be carefully considered by authorities and mitigation strategies to reduce impact on vulnerable groups, including poor women and children will be critical.

Since May 4, Tunisia has embarked on a new phase in the management of the COVID-19 pandemic: progressive and targeted lifting of the general lockdown. Borders have been reopened to travelers since June 27, bringing an increase in the number of new cases. Initially new infections were mostly imported, however after 30 July local infections started exceeding imported infections but transmissions chains were still identifiable with clusters emerging from events like weddings or in some businesses [32]. Unfortunately, the situation deteriorated further and with more than 30000 new infections in the last 4 weeks (November 2020) and 227 infections per 100000 inhabitants in the last 2 weeks, Tunisia is currently facing an extremely challenging situation of COVID-19, with an imminent risk of saturating the health system’s capacity. Authorities have imposed NPIs in this second phase too, however, stricter measures were applied much later than in the first phase when compared to numbers of cases. Additionally, the population’s compliance to measures has been much lower this time around, partially due to the Tunisia’s relatively outcomes during the first phase which has lowered people’s perception of the risk from COVID good -19. Like in other countries, another national
lockdown is considered untenable due to the huge social and economic impacts. As such, Tunisia faces a precarious situation, which will hopefully be contained through continuous strengthening of the health system response as well as stricter measures such as localized nighttime curfews that have now been imposed in some parts of the country [33].

Despite this turnaround in the situation, the Tunisian experience with the first phase of COVID-19 can be very informative for other countries. While the Tunisian response to the first phase of COVID-19 could surely have been improved in different areas, our results confirm that the interventions implemented in Tunisia, notably the general lockdown, likely had played an important role in controlling the transmission of COVID-19 and avoiding saturation of the health system. Perhaps most relevant aspect of the experience from Tunisia’s first wave is the very early application of measures. Indeed, Tunisia rapidly implemented key interventions such as the identification of suspected cases, isolation of positive cases and contact tracing with mandatory quarantine of close contacts, as well as a strict general lockdown to contain the first phase of the epidemic [16]. While some of these interventions, particularly early lockdown may be difficult to replicate, their effects on controlling infections and deaths were very notable. As such, Tunisia’s experience with first phase of COVID-19 presents useful lessons both academically as well as from a policy perspective.

Their reopening has led to a decline in vigilance, even a certain skepticism among Tunisians about the potential seriousness of the epidemic. Barrier measures were not respected. It seems far from realizing the real level of the epidemic. However, this virus is dangerous, it creates different pathologies at different ages and can leave very significant consequences, even on young populations.
NONED Working Group

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AUTHORS’ CONTRIBUTIONS

All authors contributed equally to this study. NONED Working Group collected data and managed contact tracing. All authors revised and approved the manuscript.

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Ethics approval

For the Tunisian case study, anonymized data were published. Neither ethical approval nor individual consent was not applicable.

CONFLICTS OF INTEREST

The authors have declared that they have no competing interests.
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Figure 2: Structure of the model

Figure 3: Modeling parameters and outputs

Figure 4: Impact of increasing the percentage of contact tracing
Initial number of cases=100
Initial number of cases=1000

Model II: Impact of increasing the level of compliance to isolation

Figure 5: Impact of increasing the degree of respect of isolation

Initial number of cases=100

Initial number of cases=1000
Figure 6: Impact lockdown

Figure 7: Tunisian situation in figures (June 27, 2020)

- 1169 confirmed cases
- 69137 tests
- 0 hospitalized cases
- 50 deaths
- 1029 recovered
Table 1: Parameters of overall models

| Model                  | Initial number of cases | Rt community | Efficacy of isolation | Rt after isolation | % of contacts tracing |
|------------------------|-------------------------|--------------|-----------------------|--------------------|-----------------------|
| Model I: impact of the contact tracing | i)100                   | 4            | 100%                  | 0                  | from 20% to 100%      |
|                        | ii)1000                 |              |                       |                    |                       |
| Model II: impact of compliance with isolation | i)100                   | 4            | 0%                    | 4                  | 60%                   |
|                        | ii)1000                 |              | 25%                   | 3                  |                       |
|                        |                         |              | 50%                   | 2                  |                       |
|                        |                         |              | 75%                   | 1                  |                       |
|                        |                         |              | 100%                  | 0                  |                       |
| Model III: impact of the lockdown | i)100                   | o Rt before lockdown =4 | 100%                | 0                  | 60%                   |
|                        | ii)1000                 | o Rt after lockdown =0.5 |                    |                    |                       |
|                        | iii)10000               |              |                       |                    |                       |
**Table 2: Parameters of Tunisian case study**

|                         | Initial number of cases | R0 community | Efficacy of isolation | R0 after isolation | % of contacts tracing |
|-------------------------|-------------------------|--------------|-----------------------|-------------------|----------------------|
| **Tunisian case study** | 75 cases reported to date general containment March 22, 2020 | o The Rt before and after lockdown [16] | 100% | 0 | Assumed: 80% |
**Table 3: Impact of the lockdown among Tunisian population**

|                          | Reduction Rate % (95% CI) | Male                          | Female                        | Both                          |
|--------------------------|---------------------------|-------------------------------|------------------------------|-------------------------------|
| **General population**   |                           | 85% (95% CI:83%-87%)         | 87% (95% CI:83%-91%)         | 86% (95% CI:83%-89%)         |
| **Age groups**           |                           |                               |                              |                               |
| 0-24                     | 98% (95% CI:97%-99%)      | 98% (95% CI:97%-99%)         | 98% (95% CI:97%-99%)         |
| 25-34                    | 97% (95% CI:96%-98%)      | 86% (95% CI:84%-88%)         | 92% (95% CI:90%-94%)         |
| 34-44                    | 70% (95% CI:67%-73%)      | 80% (95% CI:79%-81%)         | 75% (95% CI:72%-78%)         |
| 45-54                    | 79% (95% CI:77%-81%)      | 73% (95% CI:69%-77%)         | 76% (95% CI:72%-80%)         |
| 55-64                    | 78% (95% CI:75%-81%)      | 86% (95% CI:84%-88%)         | 82% (95% CI:78%-86%)         |
| Aged 65 years and older  | 85% (95% CI:83%-87%)      | 87% (95% CI:83%-91%)         | 88% (95% CI:86%-90%)         |
| People aged 65 years and older with chronic illnesses | 91% (95% CI:89%-93%) | 93% (95% CI:89%-97%) | 92% (95% CI:90%-94%) |