Estimating the Fatality Rate of Covid-19

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Abstract

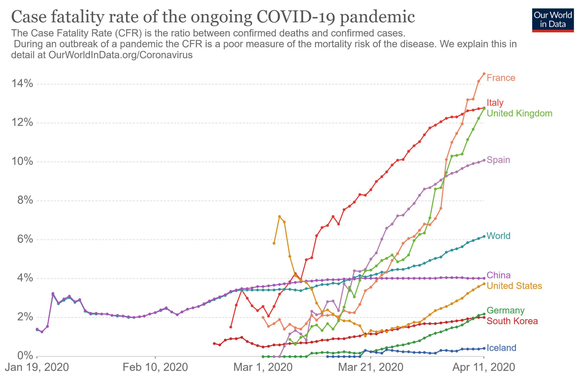
As the coronavirus disease Covid-19 rages in the world, good estimations of the disease's epidemiological parameters are crucial to help governments, hospitals, businesses, and the general public to prepare for and to stop the spread of the disease. However, the disease's fatality rate, one of the most important parameters, is not calculated properly in many websites and research papers, and thus is misleading people's understanding of the severity of the disease. In this study, we compare various definitions and methods to calculate the fatality rate and point out why they are misleading. From the study of the disease's dynamics, we propose a process to model a patient's infection, testing, confirmation, recovery or death process and develop a method to estimate the fatality rate based on available disease statistics.

Introduction

As Covid-19 rages in the world, everyone is asking the same question: how deadly is this pandemic disease? Estimating the fatality rate of Covid-19 is very important because

- Each individual person wants to know the likelihood that he or she may contract the disease, and if he or she unfortunately does, the probability that he or she could die from the disease.
- Governments and businesses want to know the best strategy to defend the disease using containment, mitigation, delaying, or flattening the curve through infection detecting, contact tracking, quarantine, isolation, lockdown, or other methods.
- Hospitals need to know the hospitalization rate and fatality rate so that they can prepare the needed space, staff, and supplies to treat patients.
- Government leaders like presidents, governors, and mayors need to know the risk of easing the lockdown in balancing the loss of lives and the loss of livelihood.

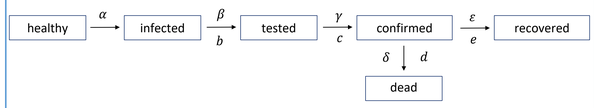
There is no doubt that Covid-19 is very deadly. However, its actual fatality rate can be very perplexing. From the following case fatality rate chart from [1], we can see that not only the case fatality rate varies dramatically among different countries, ranging from less than 1% in Iceland to more than 14% in France, but it also fluctuates significantly from the onset, the outbreak, to the closure of the disease.



In fact, the case fatality rate, which is calculated as the ratio of cumulative deaths and the cumulative confirmed cases, is only one of many definitions of the fatality rate. In this study, we will review these definitions and explain why they are misleading. We will also propose a method to calculate the fatality rate that will be more pertain to questions that individuals, governments, hospitals, businesses, and leaders ask.

The Disease Dynamics

In order to understand the fatality rate and its calculation methods, we must study the disease's dynamics, from a healthy person, to being infected, to getting tested, then to recovery or death, as shown below.



The Greek letters, α, β, γ, δ, and ε, between two states represent the probability that a person in the first state transits to the second state. Assume a healthy person has a probability of α to be infected. An infected person has a probability of β to get tested. A tested person has a probability of γ to be confirmed as positive. A confirmed patient has a probability of δ to die from the virus and a probability of ε to eventually recover. Here, $\delta + \epsilon = 1$. These probabilities represent how infectious the disease is, how well a country conduct testing to identify the infected people, how wide the virus has spread, and how successful a patient is treated.

The time to transit from one state to another is also very important. Assume it takes b days for an infected person to get a virus test, and c days to for the test result to be confirmed positive, and d days to die or e days to recover. Because each patient's situation is different, so the probabilities and times in this dynamics model are random variables. Since there are so many patients and their infection, testing and treatment process is usually not well documented. However, through tracing reports and retrospective investigative papers, we can make good estimates of the characteristics of these random variables and use them to calculate the fatality rate.

Definitions and Problems of Various Fatality Rates

The fatality rate that captures the likelihood of someone who is infected with Covid-19 will die, is the ***infection fatality rate***, and is calculated by the following formula.

$$infection\ fatality\ rate = \frac{total\ deaths}{total\ confirmed\ cases} \times 100\%$$

The ***crude mortality rate***, which measures the probability that any individual in the population will die from the disease, is calculated by the following formula.

$$crude\ mortality\ rate = \frac{total\ deaths}{total\ population} \times 100\%$$

The total deaths and total confirmed cases above may be known after the pandemic is over. However, during the outbreak, these numbers are not known yet. So we won't know these rates until the pandemic is over. We can only make estimations from available daily disease statistics.

Various Covid-19 tracking websites including [1] publish daily and cumulative confirmed cases and deaths. Many of them also publish the ***case fatality rate***, which is calculated as

$$case\ fatality\ rate\ (t) = \frac{cumulative\ deaths\ (t)}{cumulative\ confirmed\ cases\ (t)} \times 100\%$$

where t is the number of days since the beginning of the disease. Obviously, the people who die on day t are usually those people who are confirmed positive on that day. In early stages of the disease, the number of people who confirmed positive is on the rise. Because deaths usually lag positive confirmations of the disease, the set of patients who were confirmed together with the patients die on day t is usually smaller than the people who are confirmed positive on day t. Therefore, the *case fatality rate* is usually smaller than the *infection fatality rate*. At the end of the disease, as the cumulative death approaches the total death and the cumulative confirmed cases approaches the total confirmed cases, the case fatality rate will converge to the infection fatality rate.

Many factors may affect the fatality rate. The awareness of the transmission, availability of tests, clustering of the outbreak, number of hospital beds, number of doctors and nurses per million people of population, availability of medical devices like ventilators, personal protection equipment, etc, can all contribute to the fatality rate. Because these factors vary significantly among different countries, the fatality rate in different countries can vary significantly.

Even though the infection fatality rate and the crude mortality rate won't be available until the end of the pandemic, we can still make good estimations through observing data from other countries, studying tracing reports and investigative papers, and performing data analysis with the diseases dynamics.

Data from Other Countries

Other countries what have experienced all stages of the pandemic can provide valuable information for us to understand the disease dynamics. As of today, China seems to have experienced the outbreak, containment, and closure of the disease. Its daily new cases and deaths have reached a low level, and its remaining active cases have reduced to a tiny fraction of the total confirmed cases. So its case fatality rate, which stands at 3343/83014=4.03% on April 11, 2020, can be considered to be close to the its infection fatality rate.

An early tracing report published by the China National Health Commission on January 22, 2020 [2] listed the details of the first 17 deaths in Wuhan, the city where Covid-19 first outbroke. Our analysis of these 17 deaths reveals that the time from the onset of the disease's symptoms to death ranges from 6 to 41 days, with an average of 15.18 days.

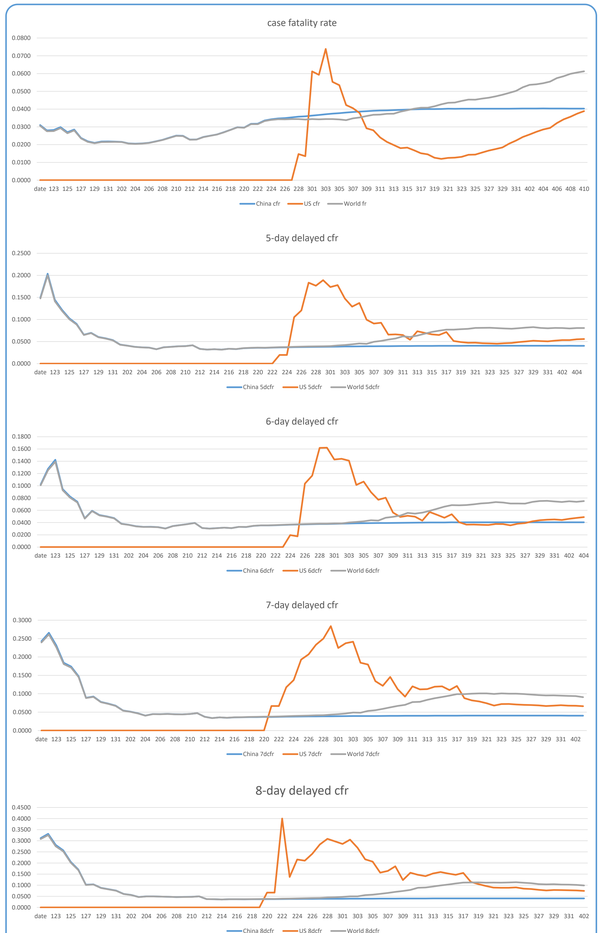
A retrospective research article published in The New England Jounral of Medicine on January 29, 2020 [3] analyzed the first 429 Covid-19 confirmed cases in Wuhan and revealed some of Covid-19's epidemiologic characteristics. It gave the details on the number of days from infection to symptom onset, the number of days from illness onset to first medical visit, the number of days from illness onset to hospitalization, and their relative frequencies.

Time Delayed Analysis

Careful study of the disease dynamics and Covid-19's epidemiologic characteristics inspired us to conduct a time-delayed analysis of the case fatality rate, i.e., to divide the cumulative deaths on day t by the cumulative confirmed cases on day $t - n$, where n is the expected number of days from a case confirmation to the death. We define the ***delayed case fatality rate with n-days*** to be

$$dcfr\ (t) = \frac{cumulative\ deaths\ (t)}{cumulative\ confirmed\ cases\ (t-n)} \times 100\%$$

The results of our study with 5 to 8-day delays are shown on the next column. The first chart is the case fatality rate without any delay. The fatality rate varies among countries dramatically and fluctuates overs time without a convergence. However, the dcfr's with a 5 to 8-day delay show much smaller fluctuations towards the end, and the dcfr with a 7-day delay shows a clear convergence of the fatality rate at the end. According to our calculated results, the infection fatality rate for China, US, and the world, is about 4.05%, 6.63%, and 9.07% respectively.



Conclusions

1. The case fatality rate published in most covid-19 tracking websites varies significantly among countries and fluctuates dramatically over time without a convergence, and thus is misleading.
2. Early tracing reports and retrospective research papers provided key information into the disease dynamics and inspired us to conduct a time-delayed analysis.
3. The delayed case fatality rate with a 7-day delay provides a clear convergence to a stable value, revealing that the expected time from case confirmation to death is about 7 days, and the infection fatality rate for China, US, and the world, is 4.05%, 6.63% , and 9.07% respectively.
4. A good estimate of the infection fatality rate calculated from the delayed case fatality rate can be used by individuals, governments, hospitals, business, and leaders to make important decisions.

References

1. Case fatality rate of the ongoing COVID-19 pandemic, https://ourworldindata.org/grapher/coronavirus-cfr, April 11, 2020.
2. China National Health Commission, Information of 17 death cases, http://www.nhc.gov.cn/yjb/s3578/202001/5d19a4f6d3154b9fae328918ed2e3c8a.shtml, Jan 23, 2020.
3. Qun Li etc, Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia, N Engl J Med 2020; 382:1199-1207, DOI: 10.1056/NEJMoa2001316.