Insuffient critical care resources led to increased COVID-19 mortality in Toronto

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Abstract

As coronavirus disease 2019 (COVID-19) spreads across the world, the intensive care unit (ICU) community must prepare for the challenges associated with this pandemic to have adequate ICU capacity and fair allocation of scarce medical resources. Data about COVID-19 cases in Toronto, extracted from OpenDataToronto is utilized to analyze how insufficient medical resources including facilities and workforces resulted in low ICU admission rates and the fatal cases of COVID-19 patients. More specifically, the possible cause of the resource scarcity, the ICU admission criteria and the hospital policies implemented in Ontario in response to the drastically increased number of patients are discussed thoroughly.

1 Introduction

SARS-CoV-2, the causative agent of coronavirus disease 2019 (COVID-19), is responsible for the largest pandemic facing humanity since the Spanish flu pandemic in the early twentieth century. Since there is no specific antiviral treatment, optimized support is the most relevant factor in the patient's prognosis. In the hospital setting, the identification of high-risk patients for clinical deterioration is essential to ensure access to intensive treatment of severe conditions in a timely manner (Hajjar et al. 2021). ICU practitioners, hospital administrators, governments, and policy makers must prepare early for a substantial increase in critical care capacity, or risk being overwhelmed by the pandemic, with a focus not just on infrastructure and supplies, but also on staff management. Critical care triage to allow the rationing of scarce ICU resources might be needed (Phua et al. 2020).

A large number of patients with COVID-19 related critical illness (CRCI) requiring ICU care has placed considerable strain on Ontario's critical care system. To expand ICU capacity, several strategies were employed including using ward beds to care for non-ventilated CRCI patients on high fractions of inspired oxygen and identifying non-traditional spaces for ICU surge capacity. Nurse to patient ratios was increased and redeployed nurses worked in team-based models of care overseen by a critical care nurse (Table 2021). Given the importance of ICU capacity and allocation of medical resources, this report utilizes open-access data from OpenDataToronto to analyze how insufficient medical resources impact the mortality of COVID-19 patients in Toronto, with regards to three factors including age group, source of infection and geographical factors.

The data is processed by R ("R Core Team" 2022) and read by readr (Hadley Wickham, Hester, and Bryan 2021) and opendatatoronto (Gelfand 2020) packages. The package dplyr (Hadley Wickham et al. 2021) is used in the majority part of analysis. The package knitr (Xie 2016) and kableExtra (Zhu 2021) contributed to table plotting while the figures were plotted by the packages including ggplot2 (H. Wickham 2016), reshape2 (Hadley Wickham 2007), tmap (Tennekes 2018), maptools (Bivand and Lewin-Koh 2021), rgeos (Bivand and Rundel 2021) and ggmap (Kahle and Wickham 2013). Package magrittr (Bache and Wickham 2020), janitor (Firke 2021), plotfunctions (Rij 2020) and tinytex (Xie 2021) helped knitting the report to pdf and have other minor functions.[1]

[1]Code and data are available at: https://github.com/jianglai8/Tao

2 Data

2.1 Data Source

This report utilizes a data set containing demographic, geographic, and severity information for all confirmed and probable cases reported to and managed by Toronto Public Health since the first case was reported in January 2020. The data are extracted from the provincial Case & Contact Management System (CCM) (Toronto 2020). Toronto Public Health (TPH), in partnership with the Province of Ontario, administrates the case and contact management component of the City's COVID-19 response (Toronto.ca 2021). The COVID-19 data set discussed in this report was extracted from the R package opendatatoronto (Gelfand 2020) in the form of csv. The data will be completely refreshed and overwritten on a weekly basis (Toronto 2020).

2.2 Methodology and Data Collection

The dataset contains information on the number of cases of COVID-19 in Toronto recorded by Toronto Public Health. A case is considered a confirmed case in three ways. Firstly, a confirmed case is identified when there is the detection of at least one specific gene target by a validated laboratory-based NAAT assay performed at a community, hospital or reference laboratory. Or there is a validated POC NAAT that has been deemed acceptable by the Ontario Ministry of Health to provide a final result. Lastly, the person demonstrated seroconversion within a 4-week interval in viral specific antibody in serum or plasma using a validated laboratory-based serological assay for SARS-CoV-2 (Health 2022). However, the standard of a confirmed case has been constantly changing since the first case was identified in January 2020. These changes in standards will lead to an increase of bias in the data.

Reported cases of COVID-19 are generally understood to only capture a subset of the actual number of cases. There are several reasons for this. Surveillance systems can only capture those cases that sought medical care (or at least sought testing), and received a diagnostic test that was determined to be "positive," that was subsequently reported back to the surveillance system. Many cases of COVID-19 are mild in severity, which reduces the likelihood that they would seek medical care and testing. Policies that restrict who can be tested (to, for example, healthcare workers, or those that exhibit a specific set of symptoms) can also cause under-ascertainment of cases. Additionally, a low percentage of individuals with COVID-19 may falsely test negative in diagnostic tests (Dougherty et al. 2021). The contagiousness, dynamics of the pathogen, and mobility of the general population also incurred the occurrence of underestimation of infection (i.e., the unidentified cases and the gap with the identified cases) that was potentially substantial in magnitude. If infectious individuals were identified timely and effectively then the efficacy of measures could be increased significantly and thus concentrating effort on the quarantining of the most infectious cases would be at work than the case of mere random control. However, such kind of mechanism was compromised during a pandemic in which transmission was established before the onset of symptoms or visible symptoms were not present (Nakamoto and Zhang 2021).

Data related to hospitalization may also fail to reflect the true numbers. As a result of the increased number of patients needing critical care beds during the pandemic, some hospitals changed their protocols regarding which types of patients were admitted to specific ICUs, e.g., admitting COVID-19 related critical illness patients to cardiac surgical ICUs. These changes happened fluidly and are not easily tracked in the database (Table 2021). Therefore the number of patients treated in ICU can be inaccurate.

2.3 Data Characteristics

The COVID-19 dataset contains information on the number of cases of COVID-19 in Toronto recorded by Toronto Public Health from January 2020 to now. There are in total 277473 observations (The dataset is updated weekly and numbers may be different after the update) and 18 attributes including 6 socio-demographic variables (id, assigned ID, gender, age group, neighbourhood name and FSA [the first segment of the postal code]), 6 virus-related variables (outbreak associated, source of infection, classification [confirmed or probable], episode date, reported date and outcome) and 6 hospitalization variables (currently hospitalized, currently in ICU, currently intubated, ever hospitalized, ever in ICU and ever intubated). Based on the interest of the study, this report mainly focuses on the discussion of 6 variables including age group, neighbourhood name, classification, source of infection, outcome and ever in ICU. As the information of whether the patients have applied for ICU is missing, the ICU admission rate in the following discussion refers to the number of patients in ICU divided by the total number of ICU patients and non-ICU patients. A sample view of the 6 attributes is shown below.

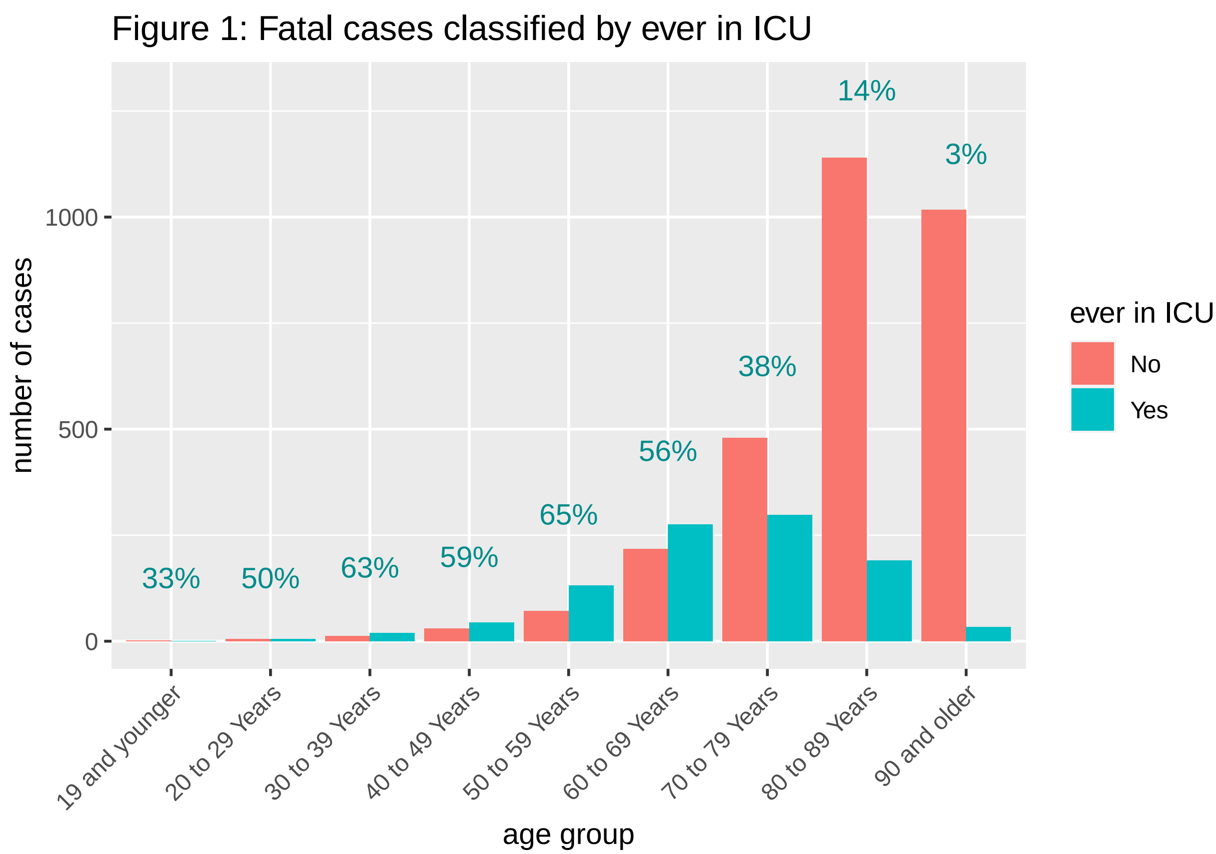
```
## # A tibble: 6 x 6
##   age_group neighbourhood_n~ source_of_infec~ classification outcome ever_in_icu
##   <chr>     <chr>            <chr>            <chr>          <chr>   <chr>
## 1 40 to 49~ Bendale          Outbreaks, Cong~ CONFIRMED      RESOLV~ No
## 2 20 to 29~ Bay Street Corr~ No Information   CONFIRMED      RESOLV~ No
## 3 19 and y~ Oakridge         Household Conta~ CONFIRMED      RESOLV~ No
## 4 19 and y~ Flemingdon Park  Outbreaks, Othe~ CONFIRMED      RESOLV~ No
## 5 20 to 29~ Willowdale East  No Information   CONFIRMED      RESOLV~ No
## 6 40 to 49~ Ionview          Household Conta~ CONFIRMED      RESOLV~ No
```

2.4 Insufficient ICU Resources

Large numbers of patients with COVID-19 related critical illness (CRCI) requiring ICU care have placed considerable strain on Ontario's critical care system, with insufficient medical resources and staffing.

According to a study conducted on Ontario's critical care system, Ontario ICUs are staffed by large interprofessional teams of healthcare professionals. The teams typically include at least one physician trained in critical care medicine, consulting physicians, nurses with specialized training and certification in critical care nursing, respiratory therapists, pharmacists, physiotherapists, occupational therapists, speech language pathologists, social workers, and spiritual counsellors or chaplains (Table 2021). Given the high complexity of the team structure, Toronto's ICU has experienced critical care workforce shortage, especially in nurses. According to the 2017/2018 CCSO biennial workforce survey, the average nursing vacancy rate in Ontario adult critical care units (the percentage of adult critical care nursing positions that were unfilled) was 5.8%. The vacancy rate climbed to 9% during the period of January–August 2020. Burnout has likely contributed to this staffing shortage. Nurses in particular have been at increased risk for burnout during the pandemic for a variety of reasons, including heightened anxiety about the risk of exposure to SARS-CoV-2 at work, an increase in patient acuity, increasing demands for overtime, reassignment to unfamiliar roles, and sustained exposure to the moral distress associated with caring for patients (Table 2021).

Except for the medical workforce, the shortage of critical care resources also limited the number of admitted ICU patients. The large number of CRCI (COVID-19 related critical illness) patients with respiratory failure has resulted in a large increase in the number of IMV patients in ICUs. In May 2021, at the peak of wave 3, the number of adult patients requiring invasive mechanical ventilation (IMV) in Ontario ICUs was 180% of the pre-pandemic historic average. Among all patients admitted to ICU with CRCI, 63.2% have required IMV, 14.7% have received renal replacement therapy (dialysis), and 3.6% have received extracorporeal membrane oxygenation (ECMO). The duration of organ support has been long: 17.9% of patients admitted to ICU with CRCI have required IMV for more than 30 days. (Table 2021). The high demand for ICU space can't be fully satisfied by the insufficient medical resources and staffing, resulting in low ICU admission rates and increased mortality related to COVID-19.



The ICU admissions of fatal cases in different age groups are displayed in Figure 1, where the histogram shows the count of cases and the numbers above the histogram indicate the percentage of cases who have been in ICU. From Figure 1, we can see that fatal cases generally have an increasing trend as age increases, with the distribution being highly left-skewed. Note that about 60% of the death cases belong to patients older than 80 years old. While at the same time, they received the lowest rates of ICU admissions (14% for patients aged between 80 and 89 years old and 3% for patients aged 90 years old and above). According to the data, people aged between 30 and 69 years old have relatively higher rates of admission than other age groups.

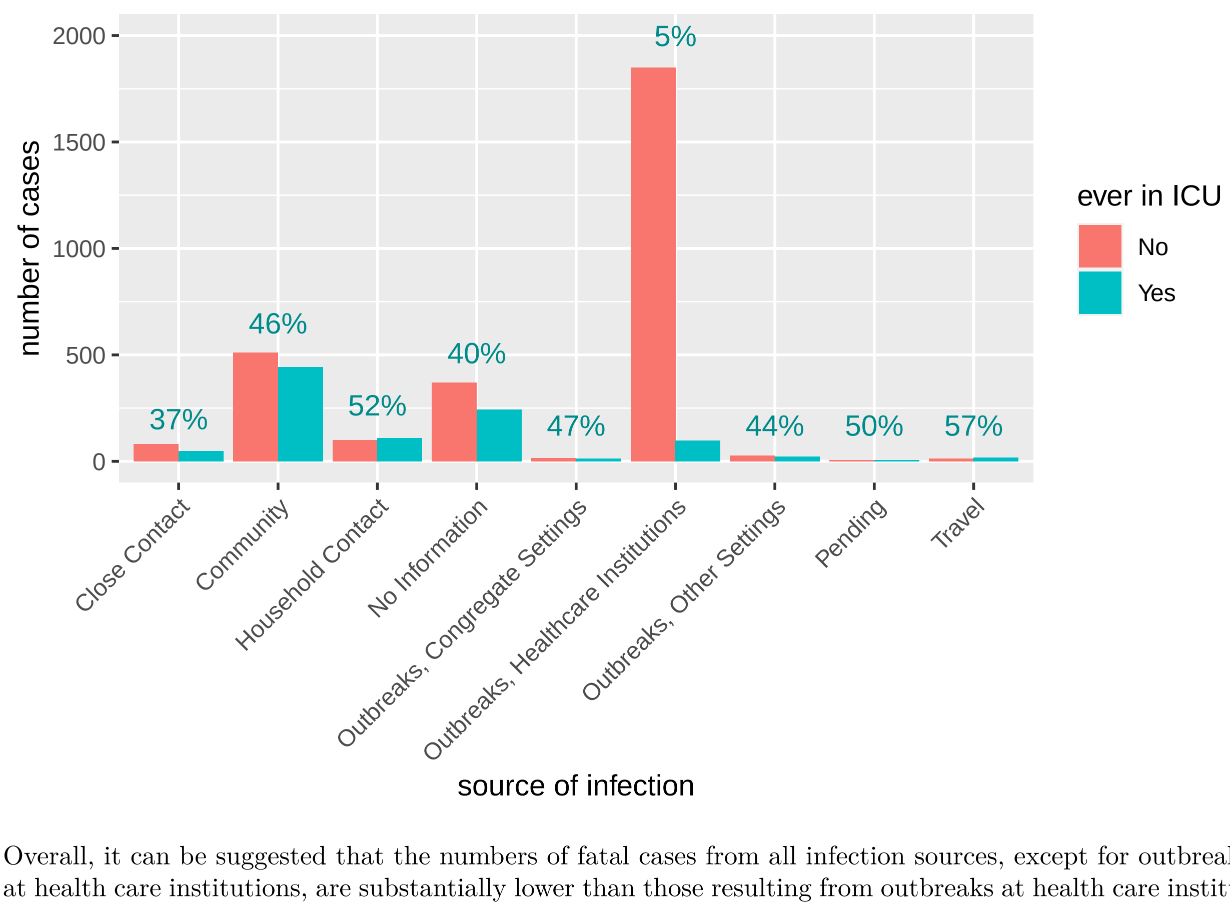
Although a lot of effort can be done to increase the ICU capacity, demand may still outpace the supply. As a consequence, a scenario can arise in which not every patient who needs ICU treatment can be admitted, and difficult decisions about the allocation of ICU beds need to be made (Haas et al. 2020). Limited time and information in a Covid-19 pandemic make it justifiable to give priority to maximizing the number of patients that survive treatment with a reasonable life expectancy and to regard maximizing improvements in length of life as a subordinate aim (Emanuel et al. 2020). A study about intensive care management of patients with COVID-19 concludes that ICU admission criteria include oxygen requirements equal or superior to 6–8l/min to reach a peripheral oxygen saturation 90–92%, respiratory failure, shock, acute organ dysfunction, and patients at high risk for clinical deterioration (Hajjar et al. 2021). According to a study predicting likelihood of ICU admission in COVID-19 patients using clinical variables, the proportions of ICU patients having asthma, diabetes, fever, cough, shortness of breath and abnormal chest x-ray results are higher than those of non-ICU patients with the same comorbidity (Li et al. 2020). Admissions to the ICU and invasive mechanical ventilation in Ontario were highest in March at 32.5% (398 hospitalized patients) and 67.6% (269 ICU patients), respectively, and decreased over the course of the pandemic to 20.6% (83 hospitalized patients) and 42.2% (35 ICU patients), respectively, in September (Table 2021).

Hospitals in Ontario implemented a number of policy actions that enabled the critical care system to meet the demands of the increased number of patients including: 1) a reduction in non-emergent surgical and procedural activity to preserve capacity for CRCI patients; 2) an increase of critical care capacity; and 3) transfers of critically ill patients within and between regions to distribute patients among provincial critical care resources. Moreover, the existing critical care workforce was not sufficient to staff these additional surge beds using traditional staffing models. In some cases, nurses were "doubled" or assigned to two patients, who in a non-surge scenario would each have had one nurse dedicated solely to their care. Additionally, many hospitals enacted policies that enabled them to provide IMV to the sickest patients with CRCI. Some converted level 2 non-vented beds into level 3 vented beds. In many hospitals, non-ventilated CRCI patients on high fractions of inspired oxygen (fiO2>50%) via high-flow nasal cannula were admitted to ward beds. Patients requiring this high level of oxygen would typically be cared for in an ICU, but during the pandemic period many of these patients were cared for in dedicated COVID-19 acute care wards. While it is difficult to quantify the number of patients who received this ICU-level care in wards, it appears that this policy enabled ICUs to preserve their ICU beds for those needing IMV. Hospitals were shifting their non-ventilated patients with CRCI to hospital wards so that they could accommodate the large numbers of patients with CRCI who required IMV (Table 2021).

2.5 Source of Infection

Figure 2 displays the number of fatal cases of COVID-19 patients from each infection source classified by ever in ICU, where the bar plots show the case count and the percentages above the bar plots indicate the proportion of cases admitted in ICU in each infection source.

Figure 2: Source of infection of fatal cases classified by ever in ICU



Overall, it can be suggested that the numbers of fatal cases from all infection sources, except for outbreaks at health care institutions, are substantially lower than those resulting from outbreaks at health care institutions. They also share similar rates of ICU admissions around 45%. Notice that a significantly large number of fatal cases resulted from outbreaks at health care institutions, which is almost the sum of cases from other infection sources. While at the same time, they received the lowest ICU admission rates around 5%. According to Toronto Public Health, An outbreak is defined as a localized increase (e.g. in an institution, or a specific ward or floor within an institution) in the rate of infection or illness, above that which is expected. Under the Ontario Health Protection and Promotion Act, healthcare institutions (hospitals, long-term care homes and retirement homes) are required to monitor staff and patients/residents for signs and symptoms of gastroenteric (e.g., nausea, vomiting, diarrhea, fever) and respiratory (e.g., cough, runny nose, sore throat, fever) infections. Healthcare institutions must also actively look for, detect and report suspected and/or confirmed outbreaks to their local public health unit (Toronto 2019). One factor that could have led to the large number of fatal cases and low rates of ICU admission from outbreaks in healthcare institutions is that the population in hospitals, long-term care homes and retirement homes tends to be the elderly. According to a report by Public Health Ontario, the median ages of confirmed COVID-19 cases associated with outbreaks reported between February 16, 2020 and June 12, 2021 in hospitals, long-term care homes and retirement homes are 60, 70 and 77 respectively (Ontario 2021). As aforementioned, patients aged over 80 years have extremely low rates of ICU admissions, resulting in more fatal cases.

2.6 Geographical Divisions

The geographical representation of the number of patients admitted to ICU classified by in total 140 Toronto neighbourhoods is displayed in Figure 3. We can see that in the areas along the Lake Ontario, there are fewer patients admitted to ICU compared to other neighbourhoods. The number of admitted patients is remarkably higher in neighbourhoods located in the northwest corner and northeast corner of Toronto.

Figure 3: Toronto neighbourhoods

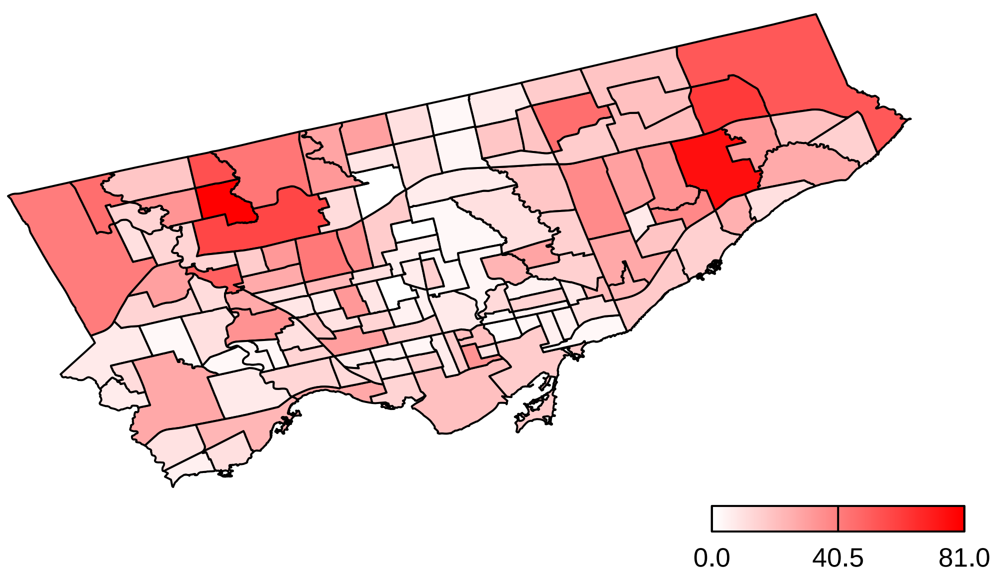


Table 1: The top ten neighbourhoods with the highest number of ICU admitted patients

Neighbourhood Name	Ever in ICU	Number of Confirmed Cases	Admission Rate	Survival Rate
Black Creek	No	3373	0.074	0.074
Black Creek	Yes	56	0.001	0.052
Downsview-Roding-CFB	No	5768	0.126	0.126
Downsview-Roding-CFB	Yes	59	0.001	0.059
Glenfield-Jane Heights	No	4431	0.097	0.096
Glenfield-Jane Heights	Yes	78	0.002	0.082
L'Amoreaux	No	3468	0.076	0.076
L'Amoreaux	Yes	43	0.001	0.038
Malvern	No	5203	0.113	0.114
Malvern	Yes	61	0.001	0.068
Mount Olive-Silverstone-Jamestown	No	4917	0.107	0.108
Mount Olive-Silverstone-Jamestown	Yes	46	0.001	0.055
Rouge	No	5175	0.113	0.112
Rouge	Yes	53	0.001	0.068
Weston	No	2775	0.060	0.060
Weston	Yes	48	0.001	0.041
Woburn	No	6042	0.132	0.132
Woburn	Yes	73	0.002	0.082
York University Heights	No	4163	0.091	0.090
York University Heights	Yes	43	0.001	0.043

The characteristics including the number of ICU cases and non-ICU cases, ICU admission rate and survival rate of the ten neighbourhoods with the highest number of admitted patients are shown in Table 1. Notice that the number of confirmed cases in these neighbourhoods is noticeably high, accounting for almost 18% of Toronto's total confirmed cases and resulting in more demand for ICU. All of the 10 neighbourhoods belong to the top fifteen neighbourhoods with the highest confirmed cases, except for Weston being the 23rd. With regard to ICU admission rate and survival rate of non-ICU patients, the ten neighbourhoods share similar rates which are generally 1%-2% and 98%-99.6% respectively. However, there are substantial differences in the survival rate of ICU patients. For example, Weston has the lowest ICU survival rate which is approximately 47.9%, while Rouge has the highest around 71.7%. The differences in ICU survival rates can be caused by a number of factors including different critical care capacities and medical resources of the healthcare institutions.

3 Conclusion

The insufficient critical care resources including both facilities and staffing resulted in more fatal cases, in particular for the elderly experiencing extremely low ICU admission rates. There have been debates on the ethics of whether we should deny ICU admission to the elderly in time of scarcity. It may be more challenging for the critical care system to rapidly increase capacity as it did during prior pandemic waves. Public health measures are needed in the short term to reduce transmission of SARS-CoV-2. Longer-term policies need to be simultaneously implemented to address the existing critical care staffing crisis. These combined efforts will help ensure that there is critical care capacity for all patients who require it, and reduce the burden on an already strained workforce (Table 2021).

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