

Patient flow dynamics in hospital systems during times of COVID-19: Cox proportional hazard regression analysis.

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Abstract

Objectives: The present study is aimed at estimating patient flow dynamical parameters and requirement of hospital beds. Secondly, the effects of age and gender on parameters were evaluated.

Patients and Methods: In this retrospective cohort study, 987 COVID-19 patients were enrolled from SMS Medical College, Jaipur (Rajasthan, India). The survival analysis was carried out from 29 Feb to 19 May 2020 for two hazards – ‘Hazard 1’ was hospital discharge and ‘Hazard 2’ was hospital death. The starting point for survival analysis of the two hazards was considered to be hospital admission. The survival curves were estimated and additional effects of age and gender were evaluated using Cox proportional hazard regression analysis.

Results: The Kaplan Meier estimates of lengths of hospital stay (Median =10 days, IQR =10 days) and median survival rate (more than 60 days due to large amount of censored data) were obtained. The Cox Model for ‘Hazard 1’ showed no significant effect of age and gender on duration of hospital stay. Similarly, the Cox Model 2 showed no significant difference of gender on survival rate. The case fatality rate 8.1 %, recovery rate 78.8% , mortality rate 0.10 per 100 person–days and hospital admission rate 0.35 per 10⁵ person-days were estimated.

Conclusion : The study estimates hospital bed requirement based on patient flow dynamic parameters. Furthermore, study concludes that average length of hospital stay were similar for patients of both genders and all age groups.

Introduction

According to World Health Organization, as on 22 Jun 2020, there were 8,860,331 confirmed cases and 465,7440 deaths due to COVID-19 were reported.¹ The dynamics and course of COVID-19 is uncertain, it is not merely possible but likely that the patient load overwhelm the medical infrastructure, including hospital beds and medical equipment. The emergence of pandemic leads to extraordinary demands on the public health system. The number of hospital beds occupied is a function of median length of hospital stay and admission rate.² The public health measures during the management of a disease pandemic should be aimed at increasing hospital bed capacity and decreasing admission rates as well as the length of the median hospital stay. Currently, no pharmaceutical interventions are safe and effective, however, best practices for disease management are based primarily on non-pharmaceutical measures, including ban on public gatherings, compulsory home stays, closure of religious and educational institutions, closure of non-essential businesses, face mask ordinances, quarantine and *cordon sanitaire* (that is, defined quarantine area from which those inside are not allowed to leave).³ A number of mathematical models have been proposed to estimate the hospital bed capacity during the pandemic.^{4,5,6} The estimation of parameters is required for further analysis by such models.

The present study is an effort to estimate dynamic parameters the COVID-19 pandemic, including median length of hospital stay, median survival time, mortality rate, recovery rate, hospital admission rate and case fatality rate in a tertiary care hospital. Further comparison of survival data across gender and age groups was performed using Cox proportional hazard analysis. In the background of given parameters the outcomes of public health policy making can be evaluated. The rationale of evidence based decision making can be fulfilled.

Materials And Methods

In this hospital based retrospective cohort study, 987 COVID-19 patients (confirmed with real time RT-PCR) were enrolled from 29 Feb 2020 to 19 May 2020 from SMS Medical College and Hospital, Jaipur, Rajasthan, India. Survival analysis was carried out to estimate median hospital stay and the median survival time. The effects of age and gender on survival patterns were evaluated using Cox proportional hazard regression analysis. Furthermore, case fatality rate, mortality rate, recovery rate, hospital admission rate were also estimated. The duration of the study was 81 days.

Data Collection:

The age, gender, date of hospital admission and discharge were recorded from case sheets of patients. The hospital outcome i.e., 'recovered', 'died' or 'admitted' was also recorded. The 'Hazard 1' was considered as hospital discharge or death. The survival time 1 (ST1) was calculated from starting point as date of hospital admission and end point as date of hospital discharge or death (Hazard 1). The cases still admitted on the last day of the study were considered under censored observations (censoring 1). Similarly, 'Hazard 2' was considered to be death in the hospital. The survival time 2 (ST2) was calculated as period between date of hospital admission (as all patients testing RT-PCR positive were hospitalized) and date of death (Hazard 2). The cases who were still admitted or recovered were considered under censored observations (censoring 2).

Data analysis:

As the data was continuously observable, the survival analysis was done with the help of Kaplan Meier (K-M) Method. The survival rate was defined as a cumulative probability distribution function (cdf) of survival time ($P[ST \geq t]$, where t is time). Survival rate 1 (SR1) and survival rate 2 (SR2) for 'Hazard 1' and 'Hazard 2' were calculated.

In order to evaluate the effects of age and sex on survival patterns, two Cox proportional hazard models (Cox Model 1 and Cox Model 2) were fitted for 'Hazard 1' and 'Hazard 2', respectively. The covariates used in both models were age and gender. Before analyzing data in the Cox model, we checked to make sure censoring did not vary significantly for different values of covariates. The hazard ratios were calculated for both models.⁷

The case fatality rate , mortality rate, recovery rate, and hospital admission rate were calculated as below⁸:

$$\text{Case fatality rate (\%)} = \frac{\text{Total number of deaths}}{\text{Total number of COVID - 19 cases}} \times 100$$

$$\text{Recovery rate (\%)} = \frac{\text{Total number of recovered}}{\text{Total number of COVID - 19 cases}} \times 100$$

$$\text{Mortality rate (per 100 PD)} = \frac{\text{Total number of deaths}}{\text{Total observed time (person - days)}} \times 100$$

$$\text{Hospital admission rate (per } 10^5 \text{ PD)} = \frac{\text{Total admissions}}{\text{population} \times \text{days}} \times 10^5$$

For the estimation of hospital admission rate, the population of Jaipur was considered to be 3.47 million.⁹

Statistical analysis:

The quantitative variables were expressed as median survival time and 95% confidence intervals with K-M based standard errors. The estimates of the Cox proportional hazard regression model. The statistical level of significance was considered at 5%. For the statistical analysis, we used JASP version 0.11. software and MATLAB 2016a.^{10,11}

Results

The mean age of COVID-19 cases was 37.08 years (SD = 17.87). The men (62.11%) had a higher proportion of COVID-19 than women (37.89 %).The distribution of age and gender indicated that younger men were most affected (Figure 1). The distribution of age and outcome showed higher proportion of deaths in the elderly (Figure 2).

Survival curves

The survival curve and K-M estimates for 'Hazard 1' were obtained (Figure 3 and Supplemental table S1).The median ST1 (median hospital stay) was 10 days .

The survival curve and K-M estimates for 'Hazard 2' were obtained (Figure 4 and Supplementary table S2).The median ST2 was more than 60 days because most of the data was censored.

Cox proportional hazard analysis

The censored and uncensored data for Hazard 1 did not differ significantly in mean age (t = 0.19, p = 0.85) , variance in age (F[857, 128] = 1.02, p = 0.91) and gender (χ^2 = 0.13, p = 0.71). Therefore, Cox Model 1 was run with age and gender as covariates.

For 'Hazard 2', there was significant difference between mean age ($t = 6.91, p < 0.05$) and variance in age ($F [79,906] = 1.37, p = 0.04$), although gender did not differ significantly ($\chi^2 = 0.10, p = 0.75$). Therefore, Cox Model 2 was set with gender the only covariate.

The Cox Model 1 for SR1 showed no significant effect of age ($HR = 1.00, p = 0.05$) or gender ($HR = 0.98, p = 0.88$). For SR2, the Cox Model 2 showed no significant effect of gender ($HR = 0.93, p = 0.77$).

Estimated Rates

The case fatality rate was estimated to be 8.1 % (95% CI: 6.4 -9.8 %). The estimation of recovery rate was 78.8% (95% CI: 76.2 – 81.3%). The mortality rate was 0.10 (95% CI: 0.08 – 0.12) per 100 person days and the hospital admission rate was 0.35 (95% CI: 0.33 – 0.37) per 10⁵ person day.

Discussion

The air we breathe, the food we eat, the house in which we live, the viruses to which we are exposed, the health services to which we have access, and the environment in which we live decides the outcome of a pandemic. The COVID-19 disease patterns are linked to migration, population movement and disease diffusion.¹² The main cause of varying rates of evolution of COVID-19 has resulted from different public health policies in various states.¹³ The primary objective for management of a pandemic is to keep the rate of evolution of cases lower, such that the disease will not overwhelm the hospital bed capacity of any state. The aim of the management is to maintain the given inequality²:

$$\text{Hospital capacity of the system} \geq \text{median LOS} \times \text{HAR} \times N$$

where LOS is length of hospital stay, HAR is hospital admission rate (in 10⁵ person days) and N is the population (10⁵ persons) dependent on the hospitals.

The present study estimated variables on the right side of the inequality. In order to maintain the inequality hospital capacity should be increased, or median hospital stay should be decreased, or admission rate should be decreased. The hospital capacity of Jaipur was found to be 6280, and right side of inequality was 108.5, that is less than hospital capacity.¹⁴ The rate of evolution for COVID-19 in Rajasthan was among the top eight states.^{15,16}

As of now no pharmaceutical agents are proved to be safe and effective for decreasing median hospital stay, The primary strategy is focused on non-pharmaceutical interventions (NPI) to decrease admission rates. Current control measures aim to reduce disease transmission through ban on public gatherings, compulsory home stays, closure of religious and educational institutions, closure of non-essential businesses, face mask ordinances, quarantine and cordon sanitaire (that is, defined quarantine area from which those inside are not allowed to leave).³ Ravaghi et al reviewed methods for determining optimum

hospital capacity. The main factors were average length of hospital stay, admission rate, discharge rate and target bed occupancy rate.²

A number of mathematical models have been used in the prediction of hospital beds during pandemic. Some are data driven models as used by Manca et al for the prediction of ICU beds.⁶ Others are empirical models, including SIR, SIRD, SEIR and SEIRD and SIDARTHE.⁴ A number of models were proposed for estimating hospital bed capacity based on queuing theory. Patient demand of beds was modeled with Poisson distribution with rate λ . The service duration has an exponential distribution $1/\mu$.⁵ The further analysis of model require the parameters like λ and μ . The present study estimates parameters for further analysis of the such models.

One approach to decreased median length of hospital stay is to triage patients based on requirement of specialized care, with beds allotted accordingly. The National Institute of Health and Care Excellence (NICE) has published an algorithm to ensure appropriate admissions to the ICU for those most in need.¹⁷ In a study of the prediction of length of hospital stay with liver blood test results, liver condition (HBsAb positive, HBcAb positive, and fatty liver disease) was carried out. The median length of hospital stay was 6 days.¹⁸ Bhandari mentioned differential neutrophil count and random blood sugar as predictors of mortality risk of COVID-19.¹⁹ One study reported that BMI, age and CRP were all related to prolongation of length of hospital stay.²⁰ Factors responsible for prolonged length of stay (LOS) in which the median was 11 days (IQR, 5–15 days) showed the most important were lower neutrophil counts, higher partial thrombin time (PT), lower D-Dimer were associated with prolonged length of stay at hospital.²¹ A novel strategy to manage patients is triage based on disease severity with management of mild patients in shelter homes. The shelter homes are large scale, temporary hospitals, assembled rapidly built by converting existing public places like stadiums, and exhibition centers into health care facilities. The important characteristics of shelter homes are rapid construction, large scale and low cost. They serve functions of isolation, basic medical care, triage, frequent monitoring and referral, essential living and social engagement.²²

Finally, the WHO Scientific and Technical Advisory Group for Infectious Hazards (STAG-IH) reviewed available information about the COVID-19 and focused on closure monitoring of epidemiology, communication strategies, intensive source control, continued containment activities, intensified active surveillance, resilience of health systems, mitigation activities during community transmission, development of serological tests, and continued research.²³

Conclusion

The present study will help facilitate evidence-based decision making process for management of the COVID-19 pandemic. The estimation of dynamic parameters of patient flow in a hospital helps in hospital management. Further, the parameters can be used by various mathematical models to predict the future requirements.

Limitations Of The Study

The effects of age on survival for 'Hazard 2' could not be analyzed because age was not matched between the censored and uncensored data. That assumption is required before focusing the Cox proportional hazard analysis. Further study will be required for that.

Abbreviations

cdf: cumulative probability distribution function

CI: confidence interval

COVID-19: coronavirus disease-19

K-M: Kaplan Meier

HR: hazard ratio

p : p value

SARS CoV-2: severe acute respiratory corona virus 2

SR1: survival rate 1

SR2: survival rate 2

ST1: survival time 1

ST2: survival time 2

Declarations

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Competing Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Declarations: The present study used de-identified data and the approval from the Institutional Ethics Committee has been taken.

Data Availability – Data is available on reasonable request from corresponding author.

Statement on participant consent: The required 'waiver of patient consent' for the above study has been approved by the Ethics Committee of SMS Medical College and Hospitals, Jaipur through letter no 524/MC/EC/2020 dated 10 Jul 2020.

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Figures

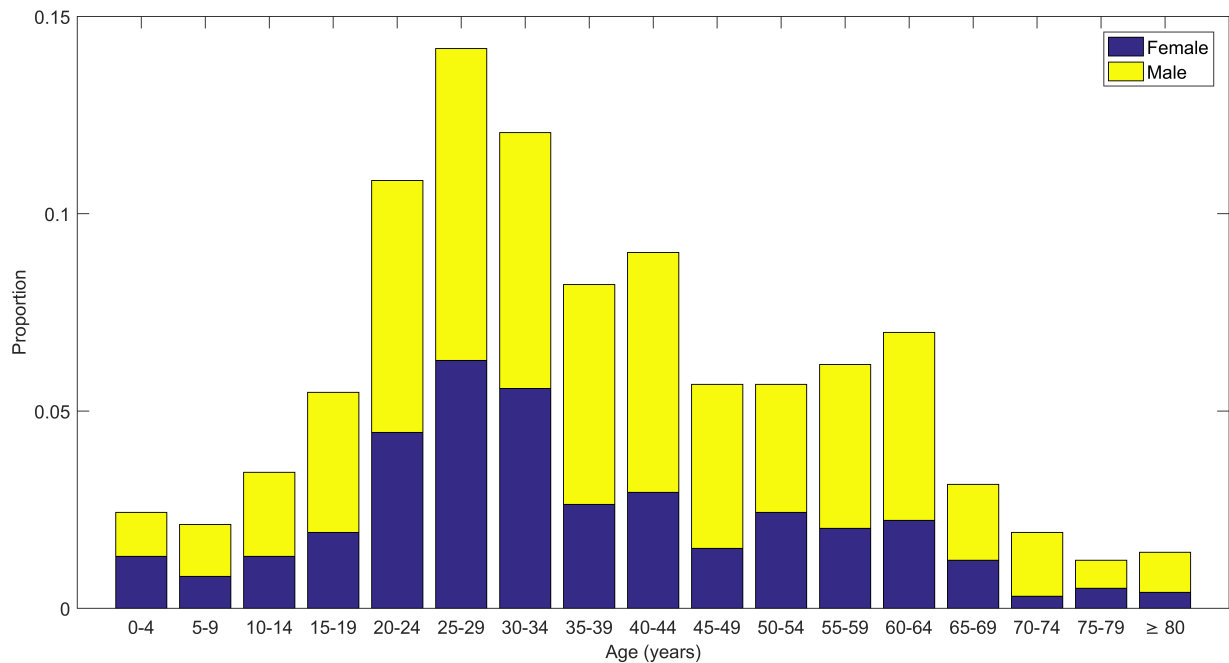


Figure 1

Stacked bar plots showing distribution of age of COVID-19 cases along with distribution of gender (male and female) within each age group.

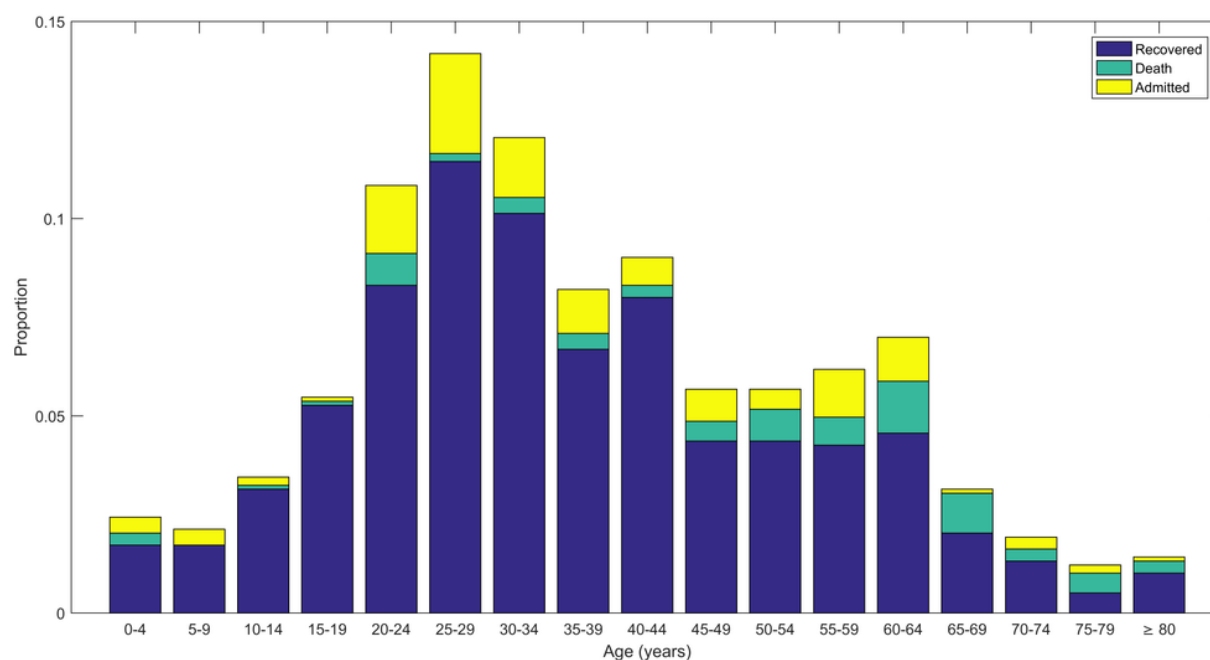


Figure 2

Stacked bar plots showing distribution of age of COVID-19 cases along with distribution of outcome ('Recovered', 'Death' and 'Admitted') within each age group.

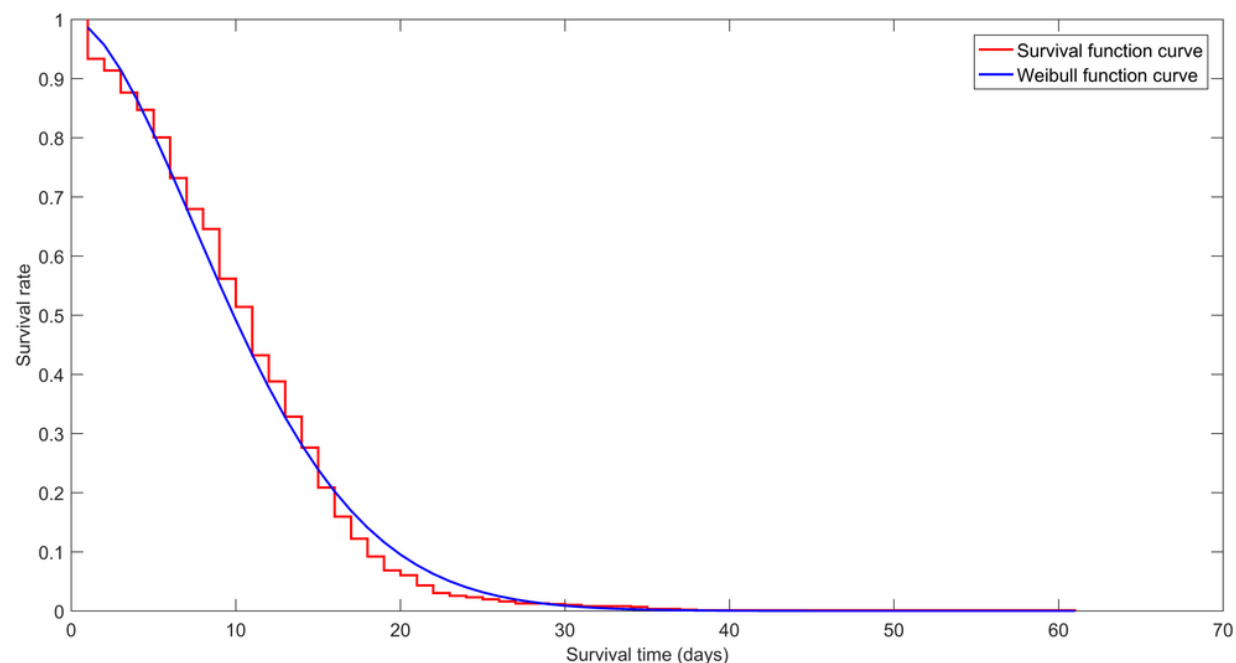


Figure 3

Survival curve (red stair case plot) for 'Hazard 1' shows Kaplan Meier estimates. The Cox Model was based on the Weibull function curve (blue line plot).

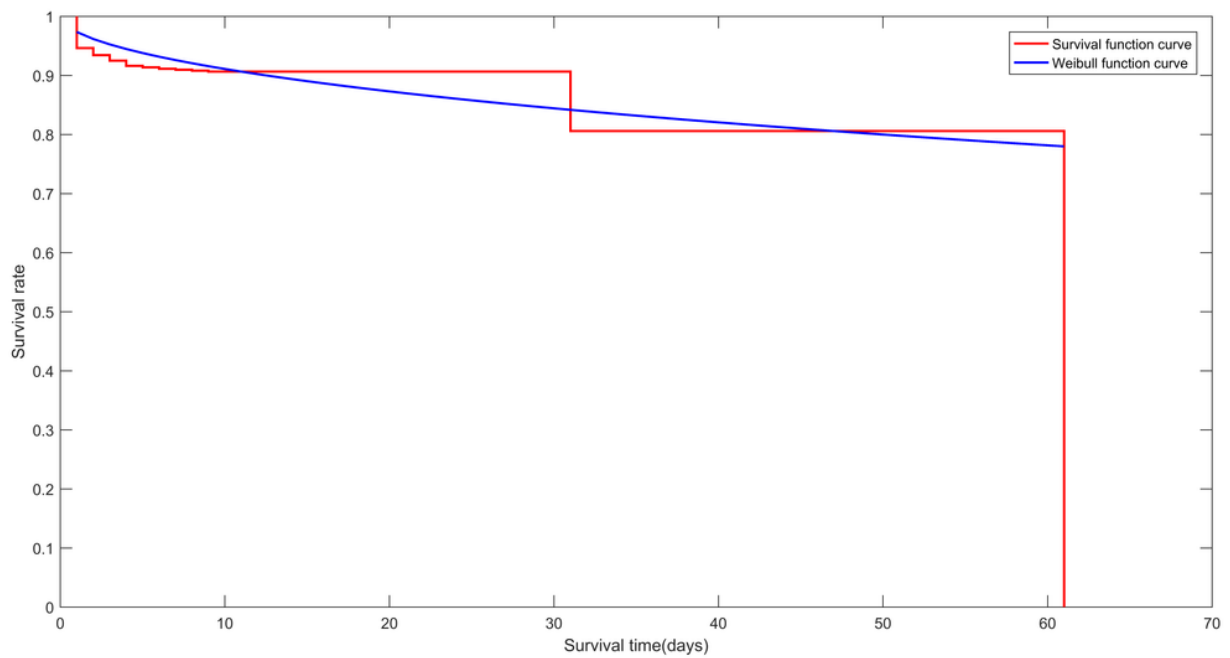


Figure 4

Survival curve (red stair case plot) for 'Hazard 2' shows Kaplan Meier estimates. The Cox Model was based on the Weibull function curve (blue line plot).

Supplementary Files

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