Research Article

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The Use of Infectious Diseases Hospital Resources During the COVID-19 Epidemic Depending on Patient Characteristics

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BACKGROUND The research of infectious hospital bed use and infectious patients' characteristics during the COVID-19 pandemic allows proposing effective management strategies for possible future epidemics.

AIM OF STUDY The analysis of infectious bed fund use at the N.V. Sklifosovsky Research Institute for Emergency Medicine (the Institute) and the characteristics of admitted patients with COVID-19 in order to determine the factors that are important for improving the medical care provision.

MATERIAL AND METHODS The data of 3365 patients treated at the Institute from March 2020 to June 2021 was used. Among them 1778 males, median age 62, average length of stay 11.2, mortality rates 17.8%, non-invasive mechanical ventilation was used for 21.5% of patients, invasive one — for 16%. For comparing the patients according to various characteristics, Fisher's exact test and Pearson's correlation coefficient were used. Length of stay was compared to exponential distribution using Pearson's chi-squared test. Comorbidity was measured using the Charlson Comorbidity Index. For all calculations R software environment was used. Survival curves were obtained via the Kaplan-Meier method. Statistical significance was less than 0.05.

RESULTS Periods of increase and decrease in hospitalization number correspond to an increase and decrease in the detection of COVID-19 cases in Moscow without lag. Intensive care for COVID-19 patients was needed in 96% of cases, readmissions to intensive care – 37%. The effective ratio of intensive care to hospital beds was determined to be higher than 2/1. The improvement in resuscitation capacity helps to avoid overload with an increase in the number of patients treated. When a patient is admitted in satisfactory condition, mortality is practically zero, while with increasing severity, mortality reaches 30–100%. The mortality rates of patients treated with the help of respiratory support is 7–40 times higher than in patients with spontaneous breathing. Higher values of the Charlson Comorbidity Index correspond to increased risks of severe course and death for patients.

CONCLUSION When providing medical care during the increase in number of infectious disease daily cases, the amount of deployed intensive care units becomes of a paramount importance. To determine the size of the bed fund, it is possible to use readily available estimates of the proportion of the population at risk of an adverse outcome from an infectious disease, based on the value of the Comorbidity Index.

Keywords: COVID-19, infectious bed capacity, intensive care units, respiratory support, Charlson Comorbidity Index

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MV - mechanical ventilation
NIMV - non-invasive mechanical ventilation

INTRODUCTION

The study of the novel coronavirus infection COVID-19 and its impact on demographics and the work of medical institutions is a hot topic today. The high transmissibility of the disease leads to rapid infection of a large number of people. In 14% of cases, patients require hospitalization due to the development of pneumonia and multiple organ failure [1]. At the same time, the patient's oxygen content in the blood decreases, and in order to further maintain life in especially severe cases, patients require respiratory support in infectious diseases hospitals, which includes invasive or non-invasive mechanical ventilation of the lungs (MV/NIMV) [2]. Thus, during the period of increasing incidence, the infectious diseases bed capacity is under serious pressure. At the beginning of the COVID-19 pandemic, studies showed that the intensive care resources available in hospitals were not enough to fully service the ever-increasing flow of patients [3].].

Also, one of the problems is the choice of treatment tactics when a patient enters a medical facility. This is the focus of works that develop practical recommendations [4, 5] and study the possibility of preventing adverse outcomes through early treatment of COVID-19 [6, 7]. Since severe cases of COVID-19 are characterized by a sharp increase in respiratory failure, the sooner the patient with a potentially severe course of COVID-19 goes to the hospital, the greater his chances of a full recovery [8]. Major research is devoted to developing the best way to treat COVID-19 at the earliest stage [7, 9, 10]. Thus, on the one hand, during an epidemic of an infectious disease, there is an overload of hospital bed capacity, on the other hand, it is necessary to hospitalize patients with severe cases of the disease as soon as possible.

The relevance of the topic of optimizing the use of infectious hospital bed capacity during an epidemic is justified by the fact that the number of bed resources should correspond to the predicted severe cases, and the possible severity should be determined at the earliest stages of infection, even before the onset of symptoms. The COVID-19 pandemic is a model of infection in which studying bed utilization may provide an example for the future.

The N.V. Sklifosovsky Research Institute for Emergency Medicine (the Institute) was chosen by the Moscow City Health Department as one of the first hospitals to organize treatment of patients with COVID-19, including due to the presence of a large intensive care bed capacity and extensive experience in providing emergency medical care. Because of the lack of infectious diseases departments at the Institute, a decision was made to repurpose separate cardiology and cardiac surgery buildings into infectious diseases departments [11]. However, due to changes in the dynamics of COVID-19 in Moscow, the number of infectious resources also changed, which is of interest for study.

Rapid and effective prediction of the severity of COVID-19 for the patient can be based on characteristics from the medical history, such as gender, age and existing comorbid diseases. Research shows that severe cases tend to be male, older, and have a number of comorbidities [12, 13]. These characteristics are included in the comorbidity index, which is used to predict the person's survival for some period of time in advance [14]. Therefore, studying the relationship between the success of COVID-19 treatment and the comorbidity index will help determine the proportion of the population that has a high probability of hospitalization.

Aim of the research: analysis of the use of infectious diseases bed capacity at the N.V. Sklifosovsky Research Institute for Emergency Medicine and the characteristics of hospitalized patients with COVID-19 to identify factors relevant to improving health care delivery.

Research objectives:

1. Study the characteristics of uneven occupancy of infectious diseases bed capacity during the COVID-19 pandemic.
2. Determine the moment of changing the bed capacity, allowing to avoid overload of the infectious bed capacity, especially in intensive care units.
3. Assess the impact of the patient's condition upon admission on the outcome of treatment for COVID-19.
4. Assess the relationship between the severity of COVID-19 and the use of respiratory support methods.
5. Identify the main characteristics of patients that influence the outcome of COVID-19.
6. Assess the possibility of using the Charlson Comorbidity Index in predicting the severity of COVID-19 in a patient.

MATERIAL AND METHODS

This research uses data from 3365 patients treated at the Institute from March 2020 to June 2021. Of these, 1778 were men, median age: 62, average bed day: 11.2; mortality: 17.8%, 21.5% were treated with non-invasive mechanical ventilation, and 16% with invasive mechanical ventilation. To compare groups of patients based on categorical characteristics, we used Fisher's exact test and Pearson's correlation coefficient, and on continuous characteristics, the Mann–Whitney U test. Length of stay was tested for exponential distribution using the Pearson's Goodness-of-Fit test. The comorbidity index was calculated using the Charlson algorithm. Survival plots were obtained using the Kaplan–Meier method. For all calculations, the free statistical software environment R was used. The criterion was considered reliable if the p-value did not exceed 0.05.

To study the impact of comorbidity on COVID-19, we calculated a comorbidity index for each patient using the Charlson algorithm [14]. The index is calculated as the sum of the points the patient currently has for chronic diseases. The worse a chronic disease affects life expectancy, the more points it contributes to the total. In addition, one point is added to the index for every 10 years of age after 40 years. The higher the total index score, the less likely the patient is to survive the next 10 years.

The work was completed in two stages. At the first stage, we assessed the use of infectious diseases bed capacity, highlighting important points to prevent overload of infectious diseases bed capacity. In the second stage, we examined the characteristics of patients on admission that influenced the status of patients with COVID-19, in particular the outcome of the disease and the use of different methods of respiratory support.

RESULTS

1. REORGANIZATION OF THE BED CAPACITY STRUCTURE

The Institute began providing assistance in the fight against COVID-19 on March 20, 2020. In this regard, not only the composition of the bed capacity and medical personnel, but also the flow of patient admissions, and the procedure for providing assistance to the population has changed dramatically. In March 2020, the cardiology department with 40 beds and the cardiac intensive care unit with 8 beds were closed, two cardiac surgery departments were reduced by 30 beds. This made it possible to open an infectious diseases department with 80 beds and two intensive care units with 10 and 12 beds. However, the initial measures did not materialize against the backdrop of an increasing flow of infectious patients and changes in the intended method of treating them. Subsequently, the infectious diseases bed capacity was changed eight more times. The dynamics of changes in bed capacity and its load against the background of patients admitted to the Institute with COVID-19 is shown in Fig. 1.

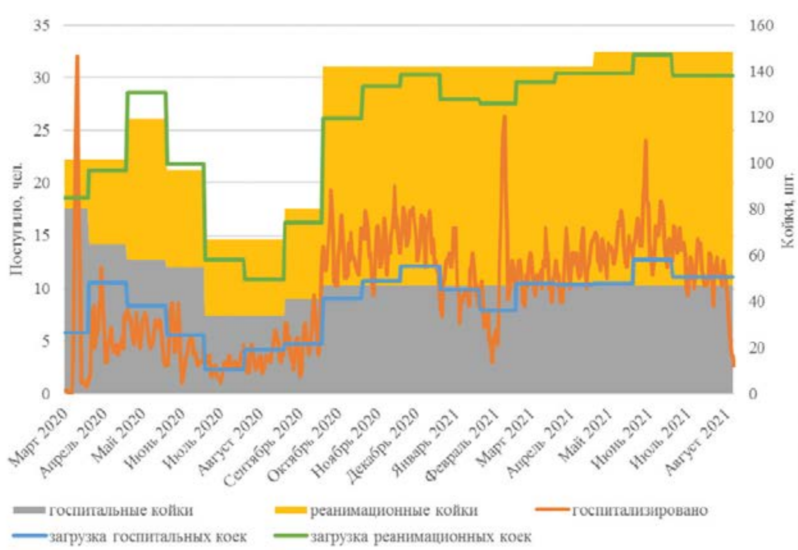

Fig. 1. Dynamics of changes in the bed capacity of infectious diseases departments and the load of infectious diseases departments at the N.V. Sklifosovsky Research Institute for Emergency Medicine from March 2020 to August 2021 and hospitalization of patients with COVID-19

When COVID-19 was detected, patients were placed in intensive care beds for dynamic monitoring of the course of the disease, regardless of the severity of their condition. If the patients' condition did not worsen within 1–2 days, they were transferred from the intensive care unit to the infectious diseases department. Due to this, out of 3,365 patients with COVID-19, 3,230 patients were treated in intensive care; intensive care for patients with COVID-19 was 96%. 1192 patients required readmission from the clinical department to intensive care due to deterioration of their condition (37%).

The maximum number of admissions was recorded at the beginning of the admission of infected patients: on March 21 and 23, 36 people were hospitalized per day. The minimum number of admissions (0–4 people per day) was noted from March 24 to April 2, 2020, since before March 24, 108 people were hospitalized in 102 infectious diseases beds (22 intensive care and 80 hospital beds). The median number of admissions per day was 10 people, the first quartile was 5 people, the third quartile was 14 people.

From March to September 2020, an average of 5 people were hospitalized per day, then from September to July 2020, an average of 13 people per day (2.6 times more). Since 96% of all the patients were admitted to intensive care, there was a need to increase the number of intensive care beds. Accordingly, the infectious diseases department was reduced to 40 beds, and the number of intensive care beds was increased to 92 in three departments (44, 14 and 34 beds). In addition, an observation unit with 4 beds and an observation intensive care unit with 3 beds were opened to sort out infected and uninfected patients.

In September 2020, the total resuscitation bed capacity was expanded from 132 to 207 beds, which made it possible to increase the resuscitation capacity of both the infectious diseases department and the specialized departments of the Institute. In connection with a new surge in the incidence of COVID-19, on May 21, 2021, the Institute opened the fourth intensive care unit for infectious patients with 6 beds. At the same time, despite the constant increase in bed capacity, the occupancy of infectious intensive care beds remained at 89%

2. ASSESSING THE CHARACTERISTICS OF HOSPITALIZED PATIENTS WITH COVID-19

A total of 3,365 patients diagnosed with COVID-19 were admitted between March 2020 and June 2021. Among infectious patients of the Institute, 15.57% of patients needed respiratory support with MV, and 21.5% with NIMV. The median age of those treated with NIMV was 6 years higher, and those treated with MV - 11 years higher than those treated without respiratory support (Mann–Whitney U test, p = 2,2·10-16). With a total average bed-day of 11.2, the average bed-day of patients on NIMV was 16 bed-days, and on MV - 7.8 bed-days (Table 1).

Table 1

Patient characteristics by respiratory support method

Indicators	Number of patients	Average bed day	Mortality, %	Median age (Q1; Q3)*, years	Average comorbidity index (without age)
Total treated	3365	11.2	17.8	62 (49; 72)	3.3 (1.56)
Underwent MV	524	7.8	88	70 (61; 80)	6.03 (3.51)
Underwent NIMV	724	16	33.8	65 (56; 73,5)	4.12 (2.07)
Received treatment without respiratory support	2329	9.6	3.2	59 (47; 69)	2.68 (1.13)

Notes: * — the first and third quartiles are indicated in parentheses. MV — mechanical ventilation; NIMV — non-invasive ventilation

Overall patient mortality was 17.8%. The mortality rate of patients treated without respiratory support was 3.2%, the mortality rate of patients who underwent NIMV was 33.8% (Fisher test, $p = 2{,}2 \cdot 10^{-16}$), and those on MV was 88% (Fisher test, $p = 2{,}2 \cdot 10^{-16}$). The mortality rate of patients on MV was 5 times higher than the average for infectious patients, and the length of hospital stay was 38% shorter.

The highest comorbidity index was observed in patients who were on MV. In relation to this group of patients, the comorbidity coefficient in patients on NIMV was 1.5 times lower (statistically insignificant, Pearson test, p = 0.15); and even lower, 2.25 times, in patients treated without respiratory support (statistically insignificant, Pearson test, p = 0.09).

As can be seen from Figure 2, among all the patients admitted to hospital with COVID-19, the proportion of men is higher in the age groups from 18 to 50 years, while in the age groups from 50 years and above the proportion of women predominates. The median age of surviving patients with COVID-19 was 59 years, 57 for men and 62 for women. The median age of deceased patients was 72 years, 70 in men and 76 in women. Mortality from COVID-19 in men was on average 2% higher (the difference is not statistically significant, since the Fisher test showed p = 0.1762). Moreover, with age, mortality in women begins to exceed 10% from the age of 70 (Fisher test, $p = 3{,}4 \cdot 10^{-8}$), and reaches a maximum of 40% in the group over 90 years. In men, mortality above 10% begins as early as 50 years of age (Fisher test, p = 0.001, statistically significant), and reaches a maximum of 57% in the group over 90 years of age (Fig. 2).

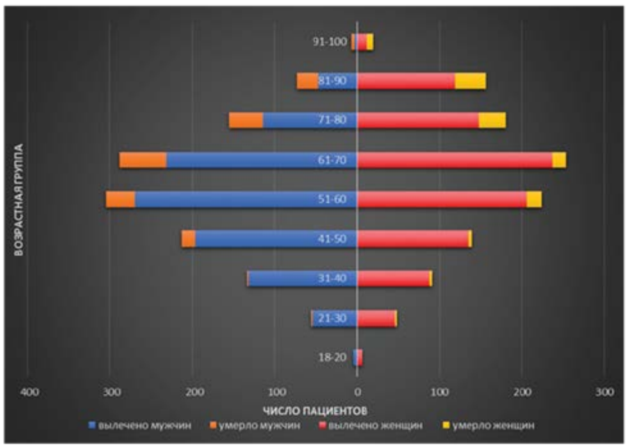

Fig. 2. Distribution of treated patients by gender, age and outcome. The columns show the absolute numbers of age-sex groups

1995 patients were admitted in satisfactory condition (mortality 0%), 577 patients – in moderate condition (mortality 0%), in severe condition - 306 patients (mortality 64%), in extremely severe condition - 484 patients (mortality 99%). Thus, patients with a higher severity level at admission had a higher mortality rate compared to the previous severity group. From 0%, it statistically significantly and monotonically increases to 99% (Pearson test, p-value 2,2·10-16). In 3 people the condition was not specified.

The distribution of time of continuous stay on MV/NIMV was studied. Logarithmic distribution of the duration of patient stay in hospital is presented in Fig. 3. Checking the type of distributions showed that the periods of time spent on MV and NIMV follow an exponential distribution without taking into account special cases of patients who stayed too long (for example, 72 bed days on MV with an average bed-day of 8). Pearson's goodness-of-fit test showed p at 0.99 for the distribution of duration on MV, and p at 0.103 for the distribution of duration on NIMV. However, the distribution of length of stay at the Institute without respiratory support did not reveal a specific type (Pearson's goodness-of-fit test: $2 \cdot 10^{-129}$). The graph of the duration of stay without respiratory support (Fig. 3c) shows that until the 6th day there is a “dip”, that is, patients most often undergo treatment without support for at least 5 days in a row, and are not discharged until this point.

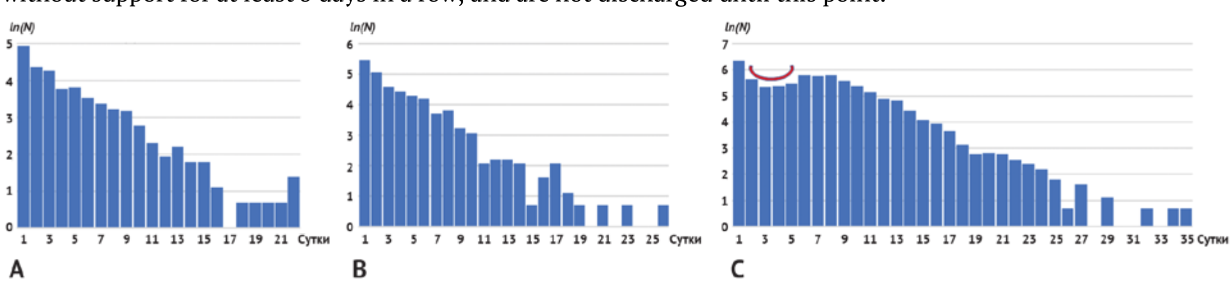

Fig. 3. Logarithmic distribution of the duration of patient stay in the hospital: A — on mechanical ventilation; B — on non-invasive ventilation; C — without respiratory support

The list of diseases we selected to calculate the comorbidity index, with scores, frequency of occurrence in patients, and mortality, is given in Table 2. As can be seen from the table, the most common concomitant diseases are myocardial infarction (28.4%), diabetes (20.4%) and kidney disease (15.5%). It should also be noted that there is a high percentage of patients who do not have diseases from the Charlson list - 41.9%.

The comorbidity index includes most diseases associated with severe cases of COVID-19. The Kaplan-Meier survival chart for hospitalized patients with COVID-19 over 30 days of hospital stay shows that patients with a high comorbidity index tend to stay in the hospital longer. The survival rate of patients with an index of 0 or 1 is 95%, and the higher the index, the lower the survival rates become, down to 14% (Fig. 4).

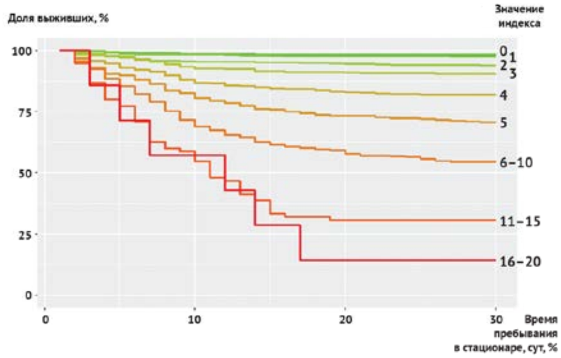

Fig. 4. Patient survival curves for 30 days of hospital stay depending on the Comorbidity Index

The comorbidity index is also consistent with the use of respiratory support methods. Figure 5 shows that in groups of patients with index 0, the proportion of patients treated with MV is 3.5%; and the higher the index, the more this share gradually increases to 55.6% (Pearson criterion, 2,2·10-16). The proportion of patients treated without the use of respiratory support methods decreases from 84.5% in the group of patients with an index 0, to 22.2% in the groups of patients with an index above 15.

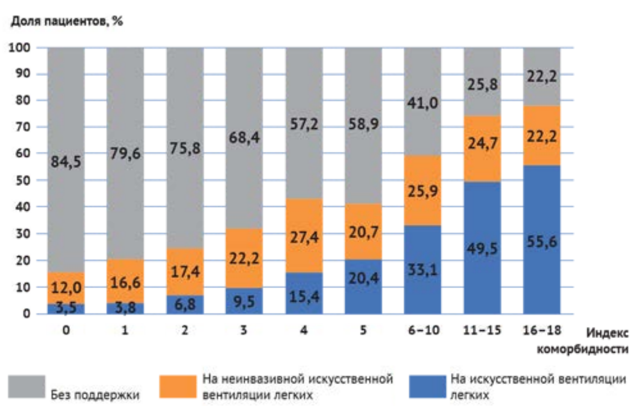

Fig. 5. Distribution of patients treated in hospital by methods of respiratory support depending on the Comorbidity Index

DISCUSSION

Despite the initial difficulties in determining the bed capacity, by the beginning of the second wave of COVID-19, an early increase in the number of infectious intensive care beds made it possible to avoid overload and ensure that those admitted received quality medical care. This expansion made it possible to increase the resuscitation capacity of the infectious diseases ward, which is important due to the high impact that resuscitation capacity has on reducing mortality [15]. At the beginning of the study period, the ratio of intensive care and hospital infectious bed capacity as 22/80 did not justify itself, while the use of a ratio of 92/40 turned out to be more effective and appropriate to the situation. Thus, during the epidemic of an infectious disease, intensive care bed capacity becomes of primary importance, since it determines the quality of medical care.

At the same time, despite the constant increase in bed capacity, the occupancy of infectious intensive care beds remained at 89%. This exceeds the standard indicators established by the Ministry of Health of the Russian

Federation on March 18, 2014, which, due to the sanitization of the bed when changing patients, determine the optimal operation of the bed for 320 days out of 365 per year, that is, 87% [16]. However, most reviews of critical care bed utilization recommend not exceeding optimal rates of 70–75% [17]. This level is necessary to ensure there is a supply of beds in case of a sudden surge in hospitalization volumes or an emergency.

The admission of patients to an infectious diseases hospital indicates a severe course of COVID-19, however, hospitalization of the patient in as satisfactory a condition as possible helps avoid an unfavorable outcome.

People over 60 years of age are at risk of death from COVID-19.

The comorbidity index demonstrated an adequate assessment of the severity of COVID-19. The study showed that comorbid diseases of patients, as well as older age, increase the likelihood of developing respiratory failure and death. However, the Charlson Comorbidity Index may not correspond well to the course of COVID-19. In our research, the mortality rates for chronic lung diseases in patients with COVID-19 were the highest, but the index score for this pathology is 1. On the other hand, tumor mortality rates are lower than for myocardial infarction, cerebrovascular disease or congestive heart failure, but tumors have a score of 2, while the listed diseases have a score of 1. Perhaps a new comorbidity index specifically for infectious diseases should be proposed, based on endothelial dysfunction [18]. In addition to changing disease scores, it is also possible to take into account the gender of the patient, since men have insufficient activation of the immune system and, as a result, a greater likelihood of death [19].

The mortality rate of patients on NIMV was 11 times higher, and in patients on MV – 28 times higher than in patients with spontaneous breathing. Thus, the need for respiratory support for patients indicates the severity of their condition.

It is possible to propose a method for determining the required volume of infectious disease bed capacity during an epidemic. A preliminary assessment of the proportion of the population that requires prompt hospitalization in an infectious diseases hospital can be carried out on the basis of the distribution of comorbid diseases by gender and age groups of the population; and the required amount of medical resources should be determined primarily by the intensive care bed capacity at a level not exceeding 90% of the possible occupancy.

CONCLUSION

The timely deployment of the required number of infectious intensive care beds during a pandemic is extremely important to ensure the greatest provision of the population with necessary medical care. At the same time, to determine the hospital and intensive care bed capacity, it is possible to use readily available estimates of the proportion of the population at risk of an adverse outcome from an infectious disease, based on the value of the comorbidity index.

FINDINGS

1. At the beginning of the epidemic, with a ratio of hospital and intensive care bed capacity of 4/1, there was an overload of intensive care bed capacity of up to 116%, and an underload of hospital bed capacity of up to 66%. The average number of admissions was limited to 5 people per day. By changing this ratio to 1/2, the average number of admissions increased to 13 people per day.
2. A change in the ratio of hospital and intensive care bed capacity should be carried out before the moment of overload of one of the departments and underload of the other. A timely increase in the resuscitation infectious disease bed capacity helps avoid its overload with an increase in the number of patients treated.
3. Depending on the severity of the patient's condition upon admission, the risk of death changes. When the patient is admitted in satisfactory condition or with moderate severity, the mortality rate is zero, while in severe and extremely severe condition it is 64% and 99%, respectively. This shows the importance of hospitalizing those infected with COVID-19 before severe symptoms appear.
4. As the patient's age increases, the probability of death increases at a rate higher than linear, while for men, on average, mortality from COVID-19 is higher than for women (19% and 17%, respectively). When the novel coronavirus infection is combined with chronic diseases, the probability of a fatal outcome increases from 3.8 to 60.9%, and depending on the chronic disease, the increase in mortality varies.
5. High values of the Charlson Comorbidity Index correspond to more frequent use of mechanical ventilation (up to 55.6% with an index above 15) and more frequent deaths (up to 86% with an index above 15).

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