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Original article

SIMULATION MODELING AND PRACTICE OF INPATIENT EMERGENCY DEPARTMENT IN COVID-19 PANDEMIC

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Abstract. The article presents the experience of using simulation modeling to optimize inpatient emergency department as an admission unit of a hospital — Center for treatment of patients with new coronavirus infection COVID-19.
It was noted that the inpatient emergency department effectively performed the functions of the inpatient department of the Center for treatment of patients with new COVID-19 coronavirus infection for a total of more than 7 months. A correct calculation of staffing and a competent use of the department "zones" ensured efficient and rapid reception of patients during both "waves" of the pandemic. The model also proved positive role of such departments with a large number of patients in a multimillion metropolis needed to be hospitalized on a daily basis.

Key words: *Center for treatment of patients with new coronavirus infection COVID-19, COVID-19 inpatient admission unit, inpatient emergency department, pandemic, simulation modeling*

Conflict of interest. The authors declare no conflict of interest

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Оригинальная статья

ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ И ПРАКТИКА РАБОТЫ СТАЦИОНАРНОГО ОТДЕЛЕНИЯ СКОРОЙ МЕДИЦИНСКОЙ ПОМОЩИ В УСЛОВИЯХ ПАНДЕМИИ COVID-19

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Резюме. *Цель исследования* – проанализировать опыт применения имитационного моделирования для оптимизации работы стационарного отделения скорой медицинской помощи (СтОСМП) в качестве приемного отделения стационара – Центра для лечения пациентов с новой коронавирусной инфекцией COVID-19 (Центр).
Материалы и методы исследования. Материалы исследования включали в себя данные: о предварительном имитационном компьютерном моделировании работы СтОСМП как приемного отделения Центра; о выполнении экспериментов на компьютерной модели для определения оптимального штатного расписания отделения; о последующем сопоставлении результатов моделирования с практическими данными.
Результаты исследования и их анализ. Результаты исследования показали, что стационарное отделение СМП эффективно выполняло функции приемного отделения Центра для лечения пациентов с новой коронавирусной инфекцией COVID-19 в общей сложности в течение свыше 7 мес, а правильный расчет штатного расписания, грамотное использование зон отделения обеспечили эффективный и быстрый прием пациентов во время обеих «волн» пандемии. В модели была также доказана позитивная роль подобных отделений при необходимости ежедневной госпитализации большого числа пациентов в многомиллионном мегаполисе.

Ключевые слова: *имитационное моделирование, пандемия COVID-19, приемное отделение стационара, стационарное отделение скорой медицинской помощи, Центр для лечения пациентов с новой коронавирусной инфекцией COVID-19*

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Introduction. The pandemic of new coronavirus infection COVID-19 was a serious challenge for the whole world. Russian medicine on the whole passed the year 2020 with dignity, having surpassed the countries that seemed to be the benchmark for the last 20-30 years in a number of areas [1-3]. Nevertheless, problems emerged in hospitals' work under new conditions. One of them is the congestion of ambulances in front of the admission departments of medical treatment organizations. Even large hospitals have encountered this problem [4-7]. Numerous photos and videos of ambulance queues circulated via social networks and caused social tension. It should be emphasized that difficulties in the work of the emergency departments of medical institutions were due to a shortage of staff and space. Despite long time that has passed since the publication of Order No. 388n of the Russian Ministry of Health "On Approval of the Procedure for Providing Emergency, including Specialized Emergency Medical Care" of July 20, 2013, number of inpatient emergency departments staffed with necessary staff and with premises for such conditions remains insufficient[1].

Modern inpatient departments of emergency medical care work effectively in emergency situations with mass admissions of patients and injured people [9-12]. However, the problem of admitting emergency patients became evident in the COVID-19 pandemic: lack of a waiting room for patients, of diagnostic beds, of "walking distance" intensive care unit, of CT scanner and of laboratory. All of this prevented medical treatment organizations from providing effective medical triage, examination and treatment of incoming patients.

One of the prerequisites for success in the fight against the new coronavirus infection was the decision of the Russian Ministry of Health to reassign federal clinics to infectious disease hospitals. This reduced the burden on regional health care. Decree No. 844-1 of the Government of the Russian Federation completely changed the work of a number of medical institutions, including St. Petersburg State Medical University named after acad. I.P. Pavlov of the Russian Ministry of Health[2]. Within a short period of time, the Center for treatment of patients with new coronavirus infection COVID-19 (hereinafter referred to as the Center) was established at the University on the basis of the Research Institute of Surgery and Emergency Medicine.

The university clinic successfully operates an inpatient emergency department. It receives up to 100 emergency patients daily. When creating it, the main recommendations contained in the order of the Ministry of Health of the Russian Federation №388n were taken into account. The medical staff of the inpatient emergency department is staffed by specialists certified in emergency medicine. The staff of the department have knowledge and skills within the professional standard, including ultrasound screening of lungs [14-15]. Nurses independently conduct daily medical triage of patients and actively participate in the therapeutic and diagnostic process. Up to 65% of those seeking emergency and urgent care receive comprehensive care at the inpatient emergency department stage and are discharged from the hospital within the first day. On the basis of the inpatient emergency departments, the University administration decided to form an admission department of the Center.

The aim of the study is to prepare an inpatient emergency department for the admission of patients with COVID-19. Our previous experience has shown the high reliability of computer simulation in assessing and planning the work of medical treatment organizations [16-18]. To achieve the above goal, the following tasks were planned: preliminary computer simulation of the unit operation; performing experiments on the computer model to determine optimal staffing; comparing the simulation results with the practical data.

Materials and research methods. First, a computer simulation of the activity of an inpatient emergency department as an admission unit of the Center was created. To reproduce the model we chose Flexsim HealthCare software, (developed in 2003, by FlexsimSoftwareProducts Inc.) which includes a special library for creating models of medical institutions. The University was expected to deploy 150 beds to care for patients with the new coronavirus infection. The experience of other medical institutions showed that in the first days of operation of the hospital there was a mass admission of patients with a subsequent decrease in their number.

The department planned the admission and medical triage of patients with a complex of therapeutic and diagnostic measures. The computer layout identified the staff, a triage area for incoming patients, as well as computer tomography (CT) and radiography rooms. The emergency department had: its own intensive care unit ("red zone"); a dynamic observation room with the possibility of minimal respiratory therapy and monitoring ("yellow zone"); and

[1] Order of the Russian Ministry of Health "On Approval of the Procedure for Providing Emergency, including Specialized Emergency Medical Care" No. 388n of June 20, 2013

[2] Professional standard of emergency medicine doctor, approved by the order of the Ministry of Labor and Social Security of the Russian Federation from March 14, 2018 №133n

a comfortable waiting room for patients in satisfactory condition ("green zone") — these rooms were planned for use based on the severity of the patients' condition. Modeling allowed to calculate the duration of patients' stay in the department, the load on the staff, and the waiting time for CT scanning as the key method of investigation in this pathology.

Based on the international recommendations published at that time, and on the Interim Guidelines for Prevention, Diagnosis and Treatment of New Coronavirus Infection COVID-19, we developed a patient admission algorithm [19-22] (Fig. 1).

This algorithm was based on the medical triage of the incoming patients, determining their further routing, and ensuring the maximum amount of examination in the admission department. At the first stage the vital functions were supposed to be assessed. The main attention was paid to the efficiency of gas exchange and hemodynamic stability. Based on the data obtained, it was planned to place the patient in one of the "zones" of the department. Further, depending on the effect of oxygen therapy and on the results of instrumental examination, further routing of the patient was determined. The average values of the duration of examinations and priorities of their performance were established, taking into account the algorithm of patient admission. The following ratio was used to form the model: 10% — intensive care patients; 70 — patients in moderate condition; 20% — patients in satisfactory condition. In this case, we assumed that mainly severe and moderately severe patients will be hospitalized by the ambulance crews to the University. Initially, a shift on duty consisting of two medical registrars, two doctors and four nurses was formed. After entering the information, a mass admission model was run with a triangular distribution of incoming patient flows of varying degrees of severity. Subsequently, the model calculations were statistically compared with actual patient stays according to the University's medical information system (MIS) QMs, for which Student's t-criterion was used to compare the mean values.

In addition, between pandemic waves, an analysis of patient admissions by COVID hospitals in St. Petersburg was performed jointly with the St. Petersburg City Ambulance Station. In spring of 2020 City Ambulance Station was faced with large crowds of ambulances in front of the emergency rooms. This blocked the effective operation of ambulance crews. The information provided made it possible to carry out a simulation of the interaction between the ambulance service and the emergency departments of COVID hospitals in the metropolis. Proposals for solving this problem were formulated.

Results of the study and their analysis. In the course of experiment #1, during the first day the model functioned without any errors, but the level of staff workload bordered on the prohibitive 97-98%. With the constant arrival of patients, queues of 5 or more people began to appear already at the stage of medical triage. At the end of the second day of model time, the process was halted due to the overload of the department. A number of experiments aimed at eliminating queues and optimizing further work were conducted on the model. The first problem was solved by strengthening the service by forming four teams of medical workers (doctor + nurse). It was also necessary to add another medical registrar to keep primary medical records of admissions. A triage nurse was assigned to ensure the primary triage process — measuring blood pressure and SpO2 of all incoming patients and assessing their ability to move independently. Under such conditions, the model functioned adequately and smoothly, and the estimated workload of the full-time staff did not exceed 75%.

In experiment #2, a new staffing schedule was applied. As a result, the deployed bed capacity of the department

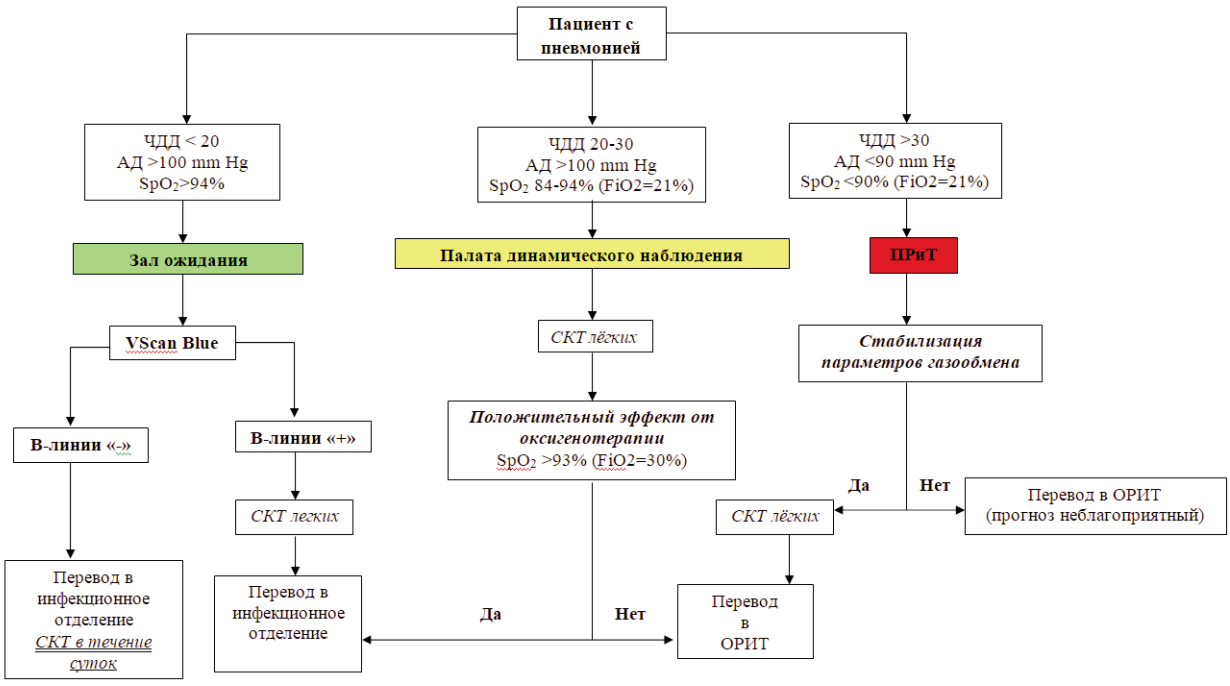

Рис.1. Алгоритм приема пациентов с подозрением на новую коронавирусную инфекцию COVID-19
Fig. 1. Algorithm of admission of patients with suspected new coronavirus infection COVID-19

(6 intensive care beds, 10 beds in the dynamic observation room, and 20 sitting places in the waiting room) was sufficient to admit up to 164 COVID-19 patients per day. The duration of stay in the department was (110±4.6) minutes, during which the patient was fully examined. If necessary, the patient was treated with artificial lung ventilation (ALV).

Using the information obtained, we decided to reinforce the staff of the admission department in the first days of the Center's opening. During the first three days, all of the staff in the inpatient emergency department worked in shifts. This made it possible to ensure, in accordance with the modeling calculations, that a sufficient number of workers was available. The 150 infectious disease and intensive care unit beds allocated to the Center were occupied by the end of the third day. During this period, the admission department efficiently performed admission, medical triage, and diagnostic activities. Thanks to this, crowding of ambulances was completely avoided. The waiting time of the patient and his transfer by the ambulance team to the doctor did not exceed 10 minutes. During the first 10 days of operation, the Center's bed capacity was doubled, reaching a total of 350 beds. As the number of hospitalized persons decreased, the number of teams on duty in the emergency department was reduced. By the end of the month, two teams and one medical registrar remained. The triage nurse was also reduced. Her functions were assigned to a nurse from one of the teams.

During the first month of operation, 865 patients with a new coronavirus infection were admitted to the emergency room. After admission, all patients underwent instrumental and laboratory examinations and received treatment. Retrospective analysis showed that the average time a patient spent in the emergency department was (115±5.8) minutes. This did not differ significantly from our estimated data obtained by simulation modeling, $p>0.05$. During the first "wave" of the disease, the Center received 1785 patients (Table).

In St.Petersburg, the number of patients with new coronavirus infection gradually decreased within three months: the University returned to its daily activities, and the admission department was transformed back into an inpatient emergency department.

The results of the COVID hospitalizations were comprehensively analyzed at various levels of the health care system. Concerns about increased waiting times for ambulance near the emergency departments of medical treatment organizations were reflected in a letter from Russian Minister of Health M.A. Murashko dated November 10, 2020, No. 30-2/I/2-17200, sent to the highest officials of the subjects of the Russian Federation.

Data from the city ambulance station allowed the authors to demonstrate the effectiveness of the inpatient emergency department used as a COVIDinpatient admission unit. During experiment №3 in the model based on real data of all city medical treatment organizations reassigned to receive patients with a new coronavirus infection, the average time of an ambulance team call was (679.2±44.1) minutes, i.e. it exceeded 11 (!) hours. More than 90% of this time the team spent in the hospital queue. Naturally, this situation created and constantly exacerbated the shortage of ambulances in prehospital period. This ultimately blocked the work of the service (Fig. 3). These data were confirmed by numerous photographs and videos demonstrating the prohibitive waiting times for ambulance crews near emergency rooms.

In experiment №4, 10 mobile wheelchair beds with the possibility of oxygen therapy and monitoring were allocated in the emergency wards of COVID hospitals. In other words, a full-fledged, albeit small, dynamic observation ward of an inpatient emergency department was formed. Even this number of beds was enough to completely eliminate queues at the entrance to the medical treatment facility (Fig. 4).

The operating principles and estimated time for such wards were taken from Experiment No. 2. This time, as we remember, was quite enough to perform the necessary complex of therapeutic and diagnostic measures established by the Temporary Methodological Recommendations "Prevention, Diagnosis and Treatment of New Coronavirus Infection (COVID-19)", version 8.1 (01.10.2020), and to determine further patient logistics within a treatment medical organization. In this experiment, the average call time was (37.5±12.2) minutes. The results once again confirmed the need for the transformation of emergency rooms into inpatient emergency departments, the effectiveness of which in emergency conditions is beyond any doubt. Unfortunately, the idea of creating dynamic observation rooms in the emergency departments of the city was not realized due to the work load of all medical and health care organizations. The second wave of COVID-19 turned out to be much larger than the first. In the first days of the Center's reopening, hospitalizations were intense. But after a week of work, the number of daily admissions became constant and fluctuated between 20-30 people (Fig. 5). (Fig. 5). This allowed us to plan the hospital's work, including determining the number of patients to be discharged daily. At the same time the intensity of the treatment process increased significantly, which was indirectly proved by the increased lethality rate in comparison with the first wave of diseases.

Due to organized medical triage in the prehospital period the number of patients requiring respiratory support increased. It should be noted that the minimum requirements for medical activities aimed at prevention, diagnosis and treatment of the new coronavirus infection COVID-19, set out in Annex 10 to Order of the Ministry of Health of Russia № 198n of March 19, 2020 (as amended on October 1, 2020) in terms of providing medical gases for 70% of the bed fund, sometimes proved to be insufficient for effective work.

The shortage of intensive care beds and infectious disease beds equipped with oxygen forced us to use the dynamic observation ward and the intensive care ward of

Таблица / Table

Показатели работы Центра во время первой и второй «волны» заболевания COVID-19

Performance of the Center during the first and second "waves" of COVID-19

Показатель / Indicator	Период работы Центра Period of operation of the Center	
	28.04.20–03.08.20	01.11.20–01.02.21
Число госпитализированных, чел. Number of hospitalized, people	1785	2120
Число пациентов, пролеченных на койках приемного отделения, чел. Number of patients treated in beds of the admission unit, people	174	432
Среднее количество койко-дней Average number of bed-days	10,6	8,9

the admission unit for longer observation and treatment of patients. They accounted for more than 20% of the total number of admissions. We admitted 348 patients in during the period of six hours to one day, 74 patients up to three days, and 10 patients for a longer period. The created infrastructure, equipment and staff ensured all necessary therapy, care and monitoring. All this became possible thanks to a fundamentally different design of the admission ward, created on the basis of the in-patient emergency department. Sufficient space, necessary equipment, staff actively involved in the therapeutic and diagnostic process — all these made it possible to treat a large number of patients without reducing the quality of treatment in everyday work.

Average time of the hospitalized patients' stay in the admission department of less than 6 h was (125±2,2) min, significantly not exceeding that during the first "wave" of the disease, p>0,05. A significant difference, as compared with the simulation results, was due to the need to wait for places in the infectious disease units.

Conclusion

Our experiments, as well as their implementation in practice, confirm the necessity of creating inpatient emergency departments on the basis of the emergency

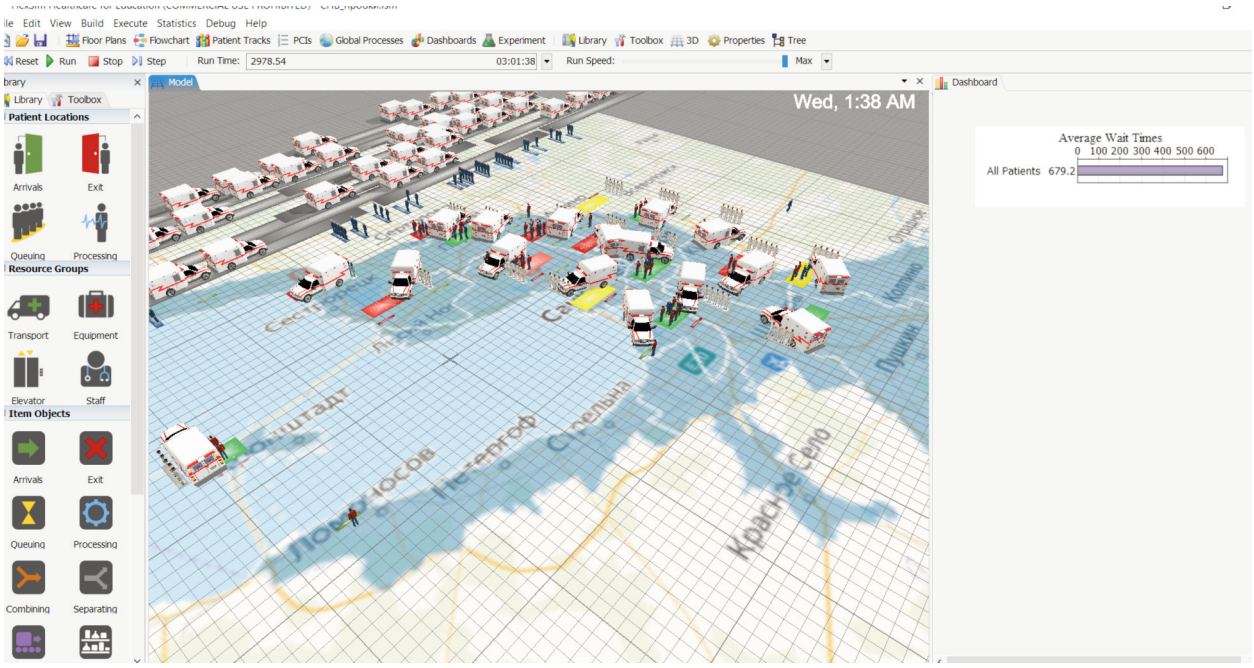

Рис. 2 . Эксперимент №3 (скриншот экрана)
* Автомобиль возле ЛМО обозначает очередь в приемное отделение стационара
Fig. 2. Experiment #3 (screenshot)
* A car near the medical treatment organisation marks the queue to the admission department of the hospital

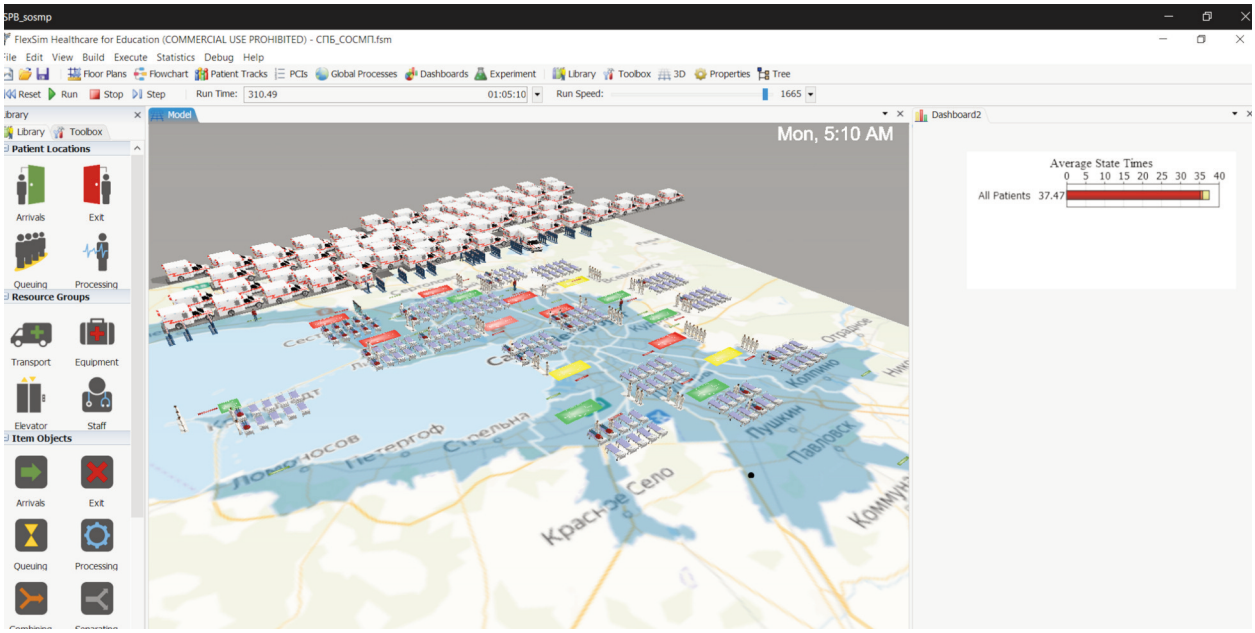

Рис. 3. Эксперимент №4 (скриншот экрана)
* Автомобиль возле ЛМО обозначает очередь в приемное отделение стационара
Fig. 3. Experiment #3 (screenshot)
* A car near the medical treatment organisation marks the queue to the admission department of the hospital

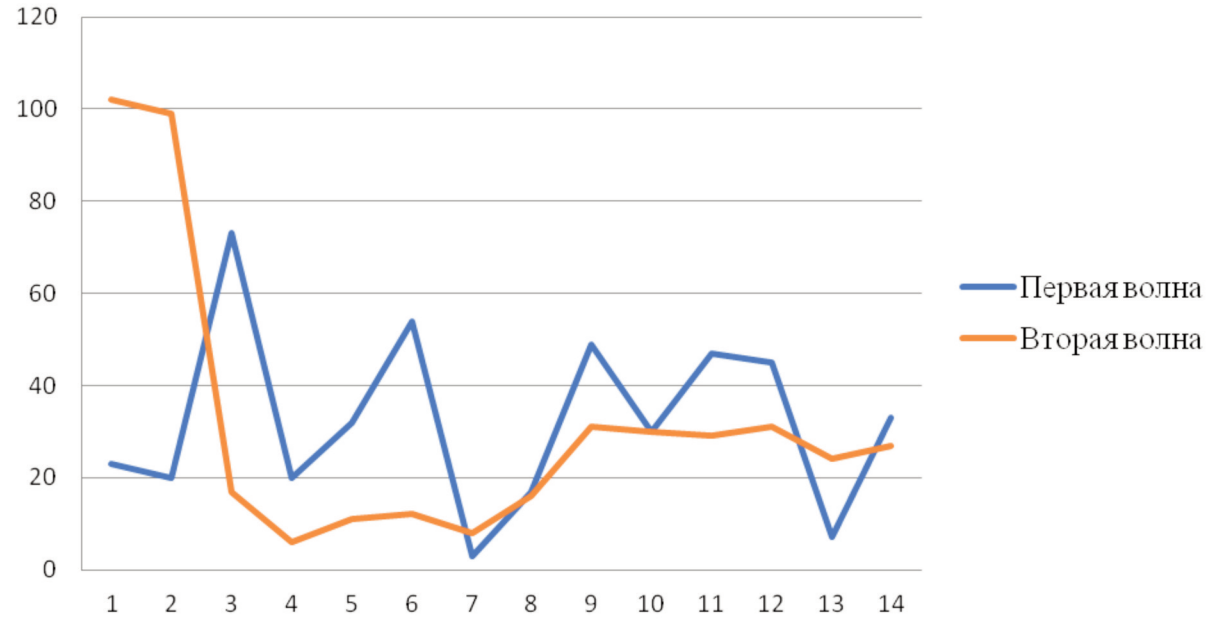

Рис. 4. Сравнение числа госпитализированных в Центр в течение первых двух недель работы в ходе первой и второй «волны» заболевания COVID-19

Fig. 4. Comparison of the number of admissions to the Center during the first two weeks of the first and second "waves" of COVID-19 disease

departments of large multidisciplinary hospitals that receive patients on emergency indications, as stated in the letter of Russian Minister of Health M.A. Murashko. This will increase their capacity and reduce the waiting time for ambulance teams.

The inpatient emergency department of the University Hospital effectively served as the Center's emergency room for the treatment of patients with new coronavirus infection for a total of more than 7 months. Simulation computer modeling performed prior to the start of operations prevented ambulance congestion. Correct staffing calculations and competent use of department "zones" ensured efficient and rapid admission of patients during both "waves" of the pandemic. The model also proved the positive role of such units when a large number of patients had to be hospitalized daily in a metropolis.

Intensive work of the Center during the second "wave" of the disease demonstrated the possibility of using dynamic observation wards and intensive care wards for long-term treatment of patients. An analysis of the three-month operation showed that 432 COVID-19 patients were treated in the emergency room for more than 6 hours. All of them required respiratory therapy of varying volume, from oxygen insufflation to ventilator assistance. Due to the availability of equipment and trained personnel, a quality treatment and diagnostic process was established. With the help of the "switched" bed fund we managed to maintain the daily discharge rate at 9.2% of the total number of beds — (23±0.75) patients per day and 8.9 average bed-days. Such an approach is completely unrealizable in the conditions of an ordinary emergency department and opens new opportunities for inpatient departments of emergency medical care in conditions of mass influx of patients on the background of the inpatient department overload.

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