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Original article

A RISK-BASED CAUSAL MODEL OF RISK FACTORS FOR INFECTION AMONG MEDICAL PERSONNEL INVOLVED IN THE CARE OF PATIENTS WITH THE NEW COVID-19 CORONAVIRUS INFECTION

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Abstract. *TThe aim of the study* is to develop and apply a mathematical model for assessing the risks of contamination of medical personnel involved in providing medical care to patients with COVID-19 in a "red zone" environment.
Materials and methods. Based on the analysis of informative signs and information on working conditions in the infectious disease department of the A.I. Burnazyan Federal Medical Biophysical Center of the Federal Medical and Biological Agency of Russia, a decision-making support system was developed to provide an objective assessment of the risks of infection for medical personnel when providing medical care in the "red zone".
Results of the study and their analysis. The influence of various risk factors for infection of medical personnel involved in the provision of medical care to patients with new coronavirus infection COVID-19 was analyzed; the most significant risk factors were identified.

Key words: *dose-effect, mathematical model of infection risk assessment, medical personnel, new coronavirus infection COVID-19, patients, red zone*

Conflict of interest. The authors declare no conflict of interest

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Оригинальная статья

РИСК-ОРИЕНТИРОВАННАЯ МОДЕЛЬ ПРИЧИННО-СЛЕДСТВЕННЫХ СВЯЗЕЙ ФАКТОРОВ РИСКА ЗАРАЖЕНИЯ МЕДИЦИНСКОГО ПЕРСОНАЛА, УЧАСТВУЮЩЕГО В ОКАЗАНИИ МЕДИЦИНСКОЙ ПОМОЩИ ПАЦИЕНТАМ С НОВОЙ КОРОНАВИРУСНОЙ ИНФЕКЦИЕЙ COVID-19

Е.А.Анненкова[1], О.А.Тихонова[1], А.П.Бирюков[1], Л.И.Баранов[1], И.Г.Дибиргаджиев[1], М.В.Шеянов[1], О.А.Касымова[1], О.В.Паринов[1]

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Резюме. *Цель исследования* – разработка и применение математической модели оценки рисков заражения медицинского персонала, участвующего в оказании медицинской помощи пациентам с COVID-19 в условиях «красной зоны».
Материалы и методы исследования. На основании анализа информативных признаков и информации об условиях труда в инфекционном отделении Федерального медицинского биофизического центра им. А.И.Бурназяна ФМБА России разработана система поддержки принятия решений, позволяющая дать объективную оценку рисков заражения медицинского персонала при оказании медицинской помощи в условиях «красной зоны».
Результаты исследования и их анализ. Проанализировано влияние различных факторов риска заражения медицинского персонала, участвующего в оказании медицинской помощи пациентам с новой коронавирусной инфекцией COVID-19; определены самые значимые факторы риска.

Ключевые слова: доза-эффект, «красная зона», математическая модель оценки рисков заражения, медицинский персонал, новая коронавирусная инфекция COVID-19, пациенты

Конфликт интересов. Авторы статьи подтверждают отсутствие конфликта интересов

Для цитирования: Анненкова Е.А., Тихонова О.А., Бирюков А.П., Баранов Л.И., Дибиргаджиев И.Г., Шеянов М.В., Касымова О.А., Паринов О.В. Риск-ориентированная модель причинно-следственных связей факторов риска заражения медицинского персонала, участвующего в оказании медицинской помощи пациентам с новой коронавирусной инфекцией COVID-19// Медицина катастроф. 2021. №3. С. 65-68. https://doi.org/10.33266/2070-1004-2021-3-65-68

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Introduction

Emergencies, including epidemics, have a major impact on health care systems. They reveal profound structural and functional problems in the organization of care for the sick and affected. The COVID-19 pandemic illustrates this at the global level. Particular attention in this situation should be paid to the socio-professional group of medical professionals. Because their qualified and coordinated actions primarily affect public health and the health of an individual [1]. The risk of occupational infection leads to disruption of the continuity of medical services. This occurs because it is necessary to establish mandatory quarantine for infected professionals and to suspend them from work. In addition, there is the problem of replacing those who are sick in the workplace. Currently, the COVID-19 pandemic makes it relevant to predict the incidence of disease in health care workers on the basis of data on other viruses from the coronavirus group.

The aim of the study is to develop and apply a mathematical model for assessing the risks of infection for the staff involved in providing medical care to patients with COVID-19 in "red zone" conditions.

Materials and methods of research. In order to mathematically model the risk of infection of medical personnel in the "red zone" we analyzed the factors influencing the work with COVID-19 patients. The basis for the formation of the space of informative attributes for the mathematical model was the data on the working conditions in the infectious disease department of the State Research Center — A.I. Burnazyan Federal Medical Biophysical Center of the Federal Biomedical Agency of Russia (A.I. Burnazyan Federal Biophysical Center). There, 223 people were involved to provide care for patients infected with SARS-CoV-2. (medical workers, drivers, disinfectors, cooks, workers, etc.), of which 166 people (medical personnel) worked in conditions of high risk of occupational contamination. The medical personnel group included 48 male and 118 female patients aged 18-69 years, mean age (48.7±1.8), of whom 57 were doctors of various specializations and 109 were nurses and auxiliary nurses. None of the study participants had previously worked in an infectious disease department setting and had no special knowledge of virology. Prior to working in the "red zone," all employees were trained in the use of personal protective equipment within a short time frame within a single-type program. They were also informed about the routes of transmission and clinical manifestations of the virus. All individuals in this group had a negative polymerase chain reaction result for SARS-CoV-2 oropharyngeal smear at the time of starting work in the infection department.

The development of a risk-based causal model of risk factors for infection among the staff involved in the care of patients with the new coronavirus infection COVID-19 was carried out in order to develop a response plan for the risk of infection among the staff. A quantitative infection risk assessment method was used. The sensitivity of model parameters was assessed to determine what additional data or knowledge could potentially reduce uncertainty and improve our understanding of the risks under investigation.

After identifying the possible risks of infection by COVID-19 virus among healthcare workers, the following were found to have the greatest impact on the probability of risks: the concentration of the virus in saliva; the concentration of viral particles released into the air by one patient cough and the number of coughs per hour; the frequency of air exchange; the number of room visits by a healthcare worker per hour; the number of patients a healthcare worker came in contact with per room visit; the time taken for each room visit and number of working hours per day (Table 1).

When building a mathematical model, we used the standards of GOST R ISO 7708-2006 ("Air Quality").

The working space of the hospital rooms was also taken into account. Most of the rooms were designed for 4 patients; the volume of the room for 4 patients was 70 m3. Symptomatic patients were considered the only source of infection in the room, with the assumption that COVID-19 is transmitted mainly through aerosols.

Viral release into the room was calculated using the formula:

$$V_i = \frac{\pi d_i^2}{6} \times 10^{-12}, \qquad (1)$$

where V_i is the volume of droplets that are ejected into the room during each coughing event; d_i – droplet diameter — assuming its spherical shape [2].

The rate of ventilation flow q_{vent} was determined by the number of air changes per hour per room volume, i.e., by the multiplicity of air changes performed in the rooms of the "red zone" according to the norms for the rooms of infectious patients:

$$q_{vent} = V \times ACH \qquad (2)$$

The daily exposure dose in PFU (plaque-forming units) for medical personnel during a room visit with patients with new COVID-19 coronavirus infection was calculated according to the formula:

$$D = C_{CoV} \times C_{saliva} \times N_{cough} \times \frac{1}{q_{vent}} \times \times V_{inhaled} \times N_{room} \times N_{pat} \times t_{spent} \times t_{work} \qquad (3)$$

where C_{CoV} – is the concentration of infection in saliva, the average value and distribution of which was calculated based on studies in work [3]; C_{saliva} – the concentration of particles in the air after one cough, which was calculated based on the particle transport model [2]; N_{cough} – number of coughs per hour, whose value range was calculated based on the particle expulsion model from the airways [4]; $V_{inhaled}$ – the air intake rate of the exposed person, equal to the human respiratory rate of 0,5 m^3/h [5]; N_{room} – number of visits to a room by a health care worker per hour; N_{pat} – number of patients with whom the health care worker came into contact per room visit; t_{spent} – time spent on each visit; t_{work} – кnumber of working hours per day – N_{room}, N_{pat}, t_{spent}, t_{work} varied depending on the job functions of health care workers. For example, nurses, on average, went around 6 wards in 1 hour, staying in each ward for 10 minutes. Their working day was 8 hours.

The formula for determining daily exposure dose (3) while wearing a mask is supplemented with the multiplier

$$p_{mask} = \frac{c_{saliva\,in}}{c_{saliva}}$$

where P_{mask} – penetration of particles through the mask, $c_{saliva\,in}$ – concentration of particles that have passed through the mask. In the "red zone" of the infection department at the A.I. Burnazyan Federal Biomedical Center, respirators with FFP3 protection were used, with a filtration efficiency of 99%, i.e. P_{mask}≈1 [6]. However, if the mask was not replaced before its efficiency was lost (up to 4 h), one must consider that the particle penetration rate through the mask becomes 100% for the entire time the mask has been worn since the loss of efficiency.

The recommended dose-effect model follows an exponential dose-effect relationship:

$$P_{inf} = 1 - e^{-kD} \quad (4)$$

where P_{inf} – probability (risk) of infection; k – optimized parameter of the dose-effect function, PFU^{-1}.

The cumulative risk of morbidity over several days of exposure was modeled as follows:

$$P_M = 1 - \left(1 - P_{inf}\right)^n \quad (5)$$

where P_M – probability of incidence; n – number of days of exposure with the probability of infection P_{inf} from daily exposure [7].

Results of the study and their analysis. A total of 26 cases (15.6%) of acute occupational COVID-19 disease confirmed by PCR or serological test were recorded during the period of the infectious disease department work. The group of those who fell ill while on duty included 10 nurses, including those working in the anesthesiology department, 9 nurse attendants, and 3 housekeepers (all female). Doctors were less exposed to occupational contamination – 4 cases (two men, two women). The average age of all the patients was (39.63±1.2) years.

All cases were locally acquired in the period from day 8 to day 21 from the opening of the infection department — during the period of learning new skills and gaining experience with this type of infection, because the experience of the staff in the new environment was insufficient.

The empirical value of the probability of infection of the personnel in the "red zone" of the infectious department of the A.I. Burnazyan Federal Medical and Biological Center during one working day with the above clinical data is $P_{inf^*} \approx$ 0,0111876. The objective conditions of personnel work in the "red zone" in which such probability of disease became a reality are reflected in the value of parameter D calculated according to formula (3). On the basis of the calculated values of P_{inf^*} and D we obtain an empirical estimate of the k parameter value by the formula:

$$k = -\frac{\ln(1 - P^*_{inf})}{D} \quad (6)$$

The value obtained is k = 13,8238987774. Thus, knowing the optimized parameter of the dose-effect function k and applying formula (5), we can estimate the risks of infection for medical personnel involved in providing medical care to patients with new coronavirus infection COVID-19, taking into account their working conditions — size and ventilation of rooms, number of patients per ward, ward visit regime, working day duration, and provision of personal protective equipment (Table 2). A comparative analysis of infection risks under different conditions revealed that the absence of personal protective equipment or its untimely replacement had the greatest influence on the risk increase — under these circumstances, the risk increased 17-fold.

The practical significance of the study is determined by its focus on improving the organizational foundations of hygienic assessment of working conditions, which will help to identify the harmful industrial effects of the new coronavirus infection COVID-19 and to develop measures to eliminate them. Of practical interest are the proposals made to preserve and improve the health of medical workers, increase their awareness of health risk factors in the conditions of "covid hospital".

Таблица 1/Table No. 1

Параметры модели

Model parameters

1	***D***	Суточная доза воздействия в PFU (бляшкообразующие единицы) для медсестер и других медицинских работников /Daily exposure dose in PFU (plaque units) for nurses and health care workers
2	C_{CoV}	Концентрация инфекции в слюне, PFU/мл Infection concentration in saliva, PFU/ml
3	C_{saliva}	Концентрация частиц в воздухе после одного кашля, 1/м^3 / Concentration of particles in the air after one cough, 1/m^3
4	N_{cough}	Количество кашлей в 1 ч / Number of coughs in 1 h
5	q_{vent}	Расход вентиляционного воздуха в помещении, м^3/ч / Ventilation air flow rate in the room, m^3/h
6	$V_{inhaled}$	Скорость забора воздуха человеком, подвергшимся воздействию, м^3/ч Rate of air intake by an exposed person, m^3/h
7	N_{room}	Количество посещений палаты медсестрой или другим медицинским работником в 1 ч Number of visits to the room by a nurse or a health care worker in 1 hour
8	N_{pat}	Число пациентов, с которыми контактировала(л) медсестра или другой медицинский работник за одно посещение палаты Number of patients visited by a nurse or a health care worker per room visit
9	t_{spent}	Время, затраченное на каждое посещение, ч Time spent on each visit, h
10	t_{work}	Количество рабочих часов в сутки Number of working hours per day
11	P_{inf}	Вероятность (риск) заражения персонала в течение одного рабочего дня /Probability (risk) of infection of personnel within one working day
12	***k***	Оптимизированный параметр функции доза-эффект, PFU^{-1} Optimized dose-effect function parameter, PFU^{-1}
13	P_m	Кумулятивная вероятность заражения в течение n рабочих дней /Cumulative probability of infection within n working days
14	***n***	Количество дней воздействий с P_m вероятностью заражения от ежедневного воздействия Number of days of exposure with P_m probability of infection from daily exposure

Таблица 2 / Table No. 2

Прогнозируемые значения заболеваемости медперсонала в «красной зоне» инфекционного отделения ФМБЦ им. А.И. Бурназяна ФМБА России

Predicted values for staff morbidity in the "red zone" of the infectious diseases department of the A.I. Burnazyan Federal Medical and Biological Center of the Federal Medical and Biological Agency of Russia

День (сутки) Day (24 hours)	Значение риска – кумулятивный риск заражения в течение нескольких дней, Pm Risk value – cumulative risk of infection over several days, Pm	Общее число сотрудников, чел. Total number of employees, people	Прогноз доли заболевших от общего числа сотрудников, % Forecast of the share of sick people in the total number of employees, %
1-й / 1st	0,0111876000	166	1,9
2-й / 2nd	0,0222500376	166	3,7
3-й / 3rd	0,0331887131	166	5,5
4-й / 4th	0,0440050111	166	7,3
5-й / 5th	0,0547003006	166	9,1
6-й / 6th	0,0652759355	166	10,8
7-й / 7th	0,0757332545	166	12,6
8-й/ 8th	0,0860735811	166	14,3
9-й / 9th	0,0962982243	166	16,0
10-й /10th	0,1064084783	166	17,7
11-й /11th	0,1164056228	166	19,3
12-й /12th	0,1262909233	166	21,0
13-й /13th	0,1360656310	166	22,6
14-й /14th	0,1457309831	166	24,2

The developed recommendations on the use of the algorithm of risk assessment for medical staff in the presence of infectious agents with airborne transmission mechanism in the working environment are aimed at reducing the health risk in this professional group. They can be used in the practical work of hygienists, hospital epidemiologists, health care organizers, and occupational safety engineers of medical treatment organizations.

Conclusion

This work was carried out under conditions of constantly changing baseline data. This is due both to the novelty of the problem under study and, accordingly, to the ever-increasing number of observations and the large number of studies on the subject, which, in turn, leads to constantly refined conclusions. In such a situation, a risk-oriented model was chosen, which corresponds to the global trends [8-11].

Our study confirmed that in order to reduce the risks of infection of medical personnel with the new COVID-19 coronavirus infection, it is necessary to educate the staff of medical treatment organizations on the strict observance of all safety measures when working with infectious patients. To raise the awareness of medical workers, it is necessary to include reports on the main health risk factors in the programs of industry and city medical conferences, taking into account regional peculiarities of the incidence of the new COVID-19 coronavirus infection.

The theoretical significance of the work performed consists in the fact that a mathematical model to estimate the risks of infection of medical personnel in specific conditions of work with infectious patients based on the quantification of key factors on which the "efficiency" of person-to-person transmission of an infectious agent depends was obtained and tested. The established correlations between the possibility of infecting medical workers and occupational factors are a subject for further research. They can be used in the development of comprehensive health care programs for medical personnel involved in the provision of medical care to patients with the new coronavirus infection COVID-19.

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