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Review

COVID-19: Risk assessment and mitigation measures in healthcare and non-healthcare workplaces

Mohamed Fawzy[1,2], **Ahmed Hasham**[2,3*], **Mohamed H. Houta**[2,4], **Mostafa Hasham**[5] **and Yosra A. Helmy**[6*]

[1] Department of Virology, Faculty of Veterinary Medicine, Suez Canal University, Ismailia, Egypt
[2] Middle East for Vaccines (MEVAC), El-Salihya El-Gededa, El-Sharkia, 44671, Egypt
[3] Department of Chemistry, Faculty of Science, Suez Canal University, Ismailia, Egypt
[4] Department of Poultry Diseases, Faculty of Veterinary Medicine, Beni-Suef University, Beni-Suef, Egypt
[5] Department of Agronomy, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt
[6] Department of Animal Hygiene, Zoonoses and Animal Ethology, Faculty of Veterinary Medicine, Suez Canal University, Ismailia 41522, Egypt

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***Corresponding authors:**
Ahmed Hasham
ahmedhasham83@gmail.com
Yosra A. Helmy
yosra_helmy@vet.suez.edu.eg

Abstract

The coronavirus disease-2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), is the third emerging human coronavirus, leading to fatal respiratory distress and pneumonia. The disease originated in December 2019 in Wuhan City, Hubei province, China. As of 23 November 2021, over 258 million cases and 5.1 million deaths have been reported in more than 222 countries and territories worldwide. The COVID-19 is under biological hazards group 4 of high risk of spreading to the community with the potential to overwhelm the health system, especially in resource limited countries. Transmission of COVID-19 within healthcare and non-healthcare facilities has been recorded. Therefore, several authorities such as the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), and other global partners issued guidance to mitigate the COVID-19 pandemic in these facilities. A global emergency due to the COVID-19 pandemic requires various studies of mitigation measures and risk assessment. The Failure Mode and Effects Analysis (FMEA) was used as a tool for risk assessment in healthcare and clinical fields that assigns a numerical value to each risk associated with failure. Therefore, in this review, the FMEA procedure was used to evaluate the COVID-19 risks and risk groups in health care and non-healthcare workplaces. Proposed mitigation measures and risk ranking tools were also summarized. The COVID-19 transmission risk should be theoretically and practically reduced by applying the best hygienic practices. However, providing safe work practices must be improved for infection control measures in healthcare and non-healthcare workplaces. Additionally, it is recommended to reassess the risk of COVID-19 infection from time to time, especially after vaccines availability.

Keywords: COVID-19; Healthcare; Mitigation; Risk Assessment; SARS-CoV-2; Workplaces, FMEA

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Introduction

The coronavirus disease-2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) was announced as a public health emergency of international concern on 30 January 2020 (WHO, 2020a). The COVID-19 has a significant public health concern causing high morbidity and mortalities in humans. Also, the virus crosses the species barriers and is transmitted from bats and pangolins to humans (Elaswad et al., 2020; Elaswad and Fawzy, 2021; Salajegheh Tazerji et al., 2020; Wu et al., 2020; Sharun et al., 2021).

The infection is spread by direct and indirect contact via respiratory droplets and/or fecal-oral routes. The basic reproduction number (R0) of COVID-19 is the number of cases directly caused by an infected individual throughout his infectious period. The transmissibility of a disease is determined by R0, which is used to determine a disease's potential to spread within a specific population. The SARS-CoV-2 can spread up to 6 feet, and the R0 was calculated to be 2-4, meaning that one infected person can spread the virus to 2-4 individuals (Zhang et al., 2020).

Transmission of COVID-19 within healthcare and non-healthcare facilities has been reported in several countries worldwide. In the United States, more than 62,000 nurses, physicians, and other healthcare providers have been infected with COVID-19, and at least 291 persons have died. Since currently, no specific treatment for COVID-19 is available, mitigation measures are the only way to prevent or reduce virus transmission (CDC, 2020a). The COVID-19 pandemic can overwhelm the health systems in different countries, particularly those in resource-limited settings. Therefore, the safety of individuals, including patients, healthcare workers, and non-healthcare workers in workplaces, is a topic of concern. The risk assessment procedures aim to eliminate the hazard or reduce it using physical controls such as personal protective equipment (PPE) and application of occupational health and safety (OH&S) management system (CWA, 2011; Demircan Yildirim, 2021). Therefore, the WHO issued guidance of required risk assessment for community health events.

The risk assessment can be addressed using the Failure Mode and Effects Analysis (FMEA) procedure which was developed in 1960 in the aerospace industry (Zhou et al., 2016; Certa et al., 2017; WHO, 2020c). The FMEA has been modified for the healthcare risk assessment purposes to be Health Care Failure Mode and Effects Analysis (HFMEA) (DeRosier et al., 2002; Faiella et al., 2018; Liu et al., 2017). This review aims to provide insights on COVID-19 epidemiology, a trial to assess the risk of COVID-19 and investigate the efficacy of strategies applied globally to control the pandemic in either health care or non-healthcare workplaces.

Epidemiological characteristics of COVID-19

Source, persistence, and transmission dynamics of COVID-19

Up to date, the main source and the definitive intermediate hosts of SARS-CoV-2 are still unclear, and different theories are still under investigation. At the beginning of the COVID-19 outbreak, the infected patients with SARS-CoV-2 were associated with the Huanan Seafood Wholesale Market in the Wuhan province of China, suggesting transmission of the disease from animals (Helmy et al., 2020). However, the continuous increase in the number of infected people who did not have any link to this market indicated disease transmission from person-to-person (CDC, 2020a). Furthermore, it was reported that the virus transmitted from bats to humans due to the high identity (96.3%) with bat coronavirus RaTG13 (Zhou et al., 2020).

The SARS-CoV-2 can replicate well in ferrets and cats and poorly in dogs, pigs, chickens, and ducks (Shi et al., 2020) (Figure 1). Also, the virus has been isolated from cats, dogs, lions, mink, and tigers (Shi et al., 2020; Salajegheh Tazerji et al., 2020). Asymptomatic infected people with the SARS-CoV-2 virus are considered a potential source for the virus spread to healthy individuals, consequently resulting in an increased risk of disease transmission between humans (Helmy et al., 2020). Besides, the virus is highly resistant and can survive on several surfaces, including plastic, disposable gowns, surgical gloves, masks, paper, steel, glass, wood, ceramic, and aluminum for 2 to 9 days as well as at low temperature (4°C) for 28 days (Kampf et al., 2020). This explains the high infection rates among health and non-health workers.

SARS-CoV-2 is similar to other coronaviruses that can be transmitted from human to human by direct and indirect contact (Helmy et al., 2017). The virus can be transmitted through coughing or sneezing of the respiratory droplets from an infected person. It can also be transmitted after touching surfaces contaminated with the virus, then touching the eyes or mouth with contaminated hands (CDC, 2020b). There is also a possibility for the virus to be transmitted through the fecal-oral route, fomites, blood-borne, from mother to child, and from animal to humans (Holshue et al., 2020; Lai et al., 2020; WHO, 2020d).

Clinical features and high-risk groups for COVID-19

The COVID-19 infection in humans is characterized by flu-like symptoms: dry cough, fever, fatigue, headache, chills, shortness of breath, sore throat, chest pain, and muscle pain. In some cases, patients also experienced nausea, runny nose, vomiting, and diarrhea (Wang et al., 2020). Fever has been reported in 83% of the patient, cough in 82%, shortness of breath in 31%, muscle ache in 11%, confusion in 9%, headache in 8%, sore throat in 5%, runny nose in 4%, chest pain in 2%, diarrhea in 2%, and nausea and vomiting in 1% (Huang et al., 2020) (Figure 2). Mostly, mild infections can last up to 2 weeks. This is considered the main reason for virus dissemination and transmission on a large scale from person to person.

Complications such as pneumonia, kidney failure, and death can occur in severe cases (disease can last 3 to 6 weeks) (Huang et al., 2020). Some patients also suffer from ischemic changes in the fingers and toes (Lin et al., 2020). The onset of the disease symptoms to death ranges between 2 and 8 weeks (Wang et al., 2020). The incubation period ranges between 2 days to 2 weeks and, in some cases, can reach up to 27 days (Bai et al., 2020). It has been reported that 80.9% of the patients suffering from the mild phase of the disease (flu-like symptoms) and recovered at home, 13.8% of the patients have developed shortness of breath and pneumonia, 4.7% of cases are severe and suffered from respiratory failure and septic shock which leading to organs failure, and about 2% of the cases were fatal (Bai et al., 2020).

Many factors can affect the spread of COVID-19 between individuals and increase the risk of transmission and the number of infected cases, including contact with healthcare workers caring for patients with COVID-19 and contact with patients who are diagnosed positive for SARS-CoV-2 virus infection (Helmy et al., 2020).

The workplaces are classified as very high-risk group (e.g., health workers), high-risk group (healthcare supportive team), medium and low-risk groups who represent the vast majority of workplace types (Koh, 2020; Semple and Cherrie, 2020; Yen et al., 2020a). The high-risk groups with high COVID-19

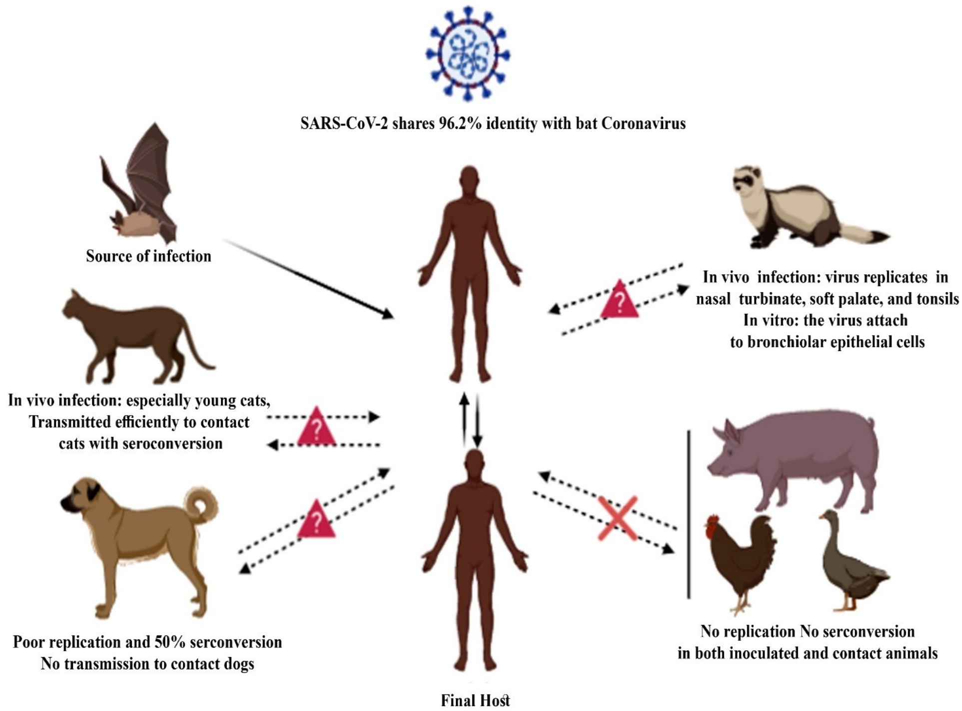

Figure 1: The proposed mode of transmission of SARS-CoV-2 between different hosts.

fatality rates within each category include older people and immunocompromised patients suffering from cardiovascular disease, hypertension, diabetes, and chronic respiratory disease (CDC, 2020a). The fatality rate was higher (14.8%) in older patients (>80 y), 8% in patients between 70-79 y, 3.6% in patients between 60-69 y, 1.3% in patients between 50-59 y, 0.4% in patients between 40-49 y, 0.2% in patients between 10-39 y. However, until now there are no fatalities reported in patients under 10-year-old. Furthermore, a higher fatality rate was reported in males (2.8%) compared to females (1.7%) (Wang et al., 2020; WHO, 2020a).

Current status of COVID-19 pandemic

In-mid January 2020, the disease began to transmit to other Asian countries such as Thailand and Japan through people visiting the Huanan Seafood Wholesale Market, then it spread to more than 18 countries. Therefore, the WHO announced the COVID-19 as a Public Health Emergency of International Concern (CDC, 2020a; WHO, 2020a). In mid-March 2020, more than 73% of the confirmed cases globally have been reported in mainland China (WHO, 2020c).

Thereafter, the globally reported cases outside China have shown a drastic increase within a short time. Consequently, on 11 March 2020, the WHO announced COVID-19 as a pandemic disease. Two days later, the WHO stated Europe to be the new center of the pandemic due to the increasing number of confirmed cases and deaths in Italy (WHO, 2020a). On 23 March 2020, the highest number of deaths was reported in Italy, followed by China, while on 30 March 2020, the highest number of cases reported in the USA, followed by Italy. Notably, on 13 April 2020, the number of confirmed cases of SARS-CoV-2 increased 1.7 times, while the number of deaths increased 2.5 times in the USA (Helmy et al., 2020). As of 23 November 2021, the virus spread to 222 countries and territories with 258,479,352 confirmed cases, 233,966,967 recovered cases, and 5,176,216 deaths worldwide with the higher occurrence and fatalities in the USA (WHO, 2020e). Starting from 23 November 2021, the virus spread to approximately 222 countries and territories with 258,479,352 confirmed cases, and 5,176,216 deaths worldwide with higher prevalence and deaths in the United States.

Risk assessment and expected hazards of COVID-19 in different workplaces

Risk assessment in different workplaces

One of the appropriate tools to control the introduction and spread of infectious diseases is performing a risk assessment to stratify community safety threats and to monitor agencies' responses (Ostrom and Wilhelmsen, 2012; Settembre-Blundo et al., 2021). The WHO guidance for conducting the required risk assessment for community health events is a helpful tool for identifying risks. Wherever potential, risks should be removed through the choice of control measures and dealing with bio-agents. If risks cannot be eliminated, they should be reduced by using physical controls and/or through systems of work and PPE (CWA, 2011).

Additionally, occupational health and safety management systems are intended to empower the organization to be responsible for safe and healthy workplaces, avoid work-related injury and disease (Darabont et al., 2018). The European directive 2000/54/CE and WHO classify the biological hazards

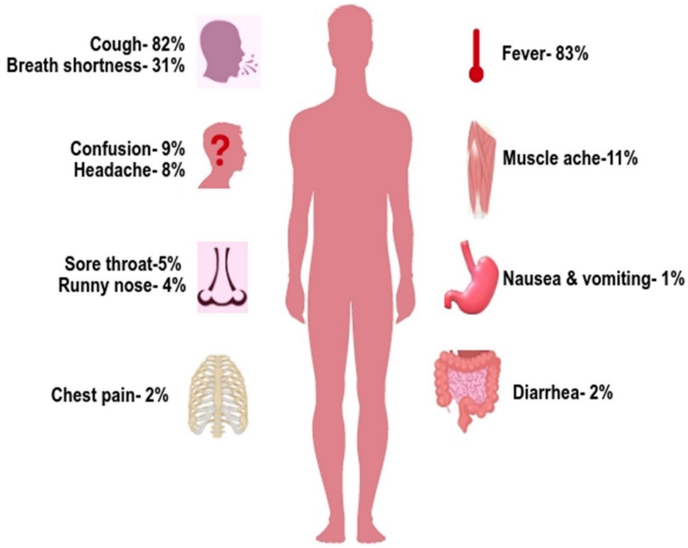

Figure 2: Clinical features of COVID-19 infection

(pathogens) into four groups according to the level of infection risk and the characteristic hazards of the organism (Băbuţ et al., 2020). The COVID-19 was categorized under "Biological hazards–Group 4" which means a high risk of spread to the community.

Inhibiting bio-agents risks is obligatory by law according to Directive 2000/54/EC of the European Parliament and of the Council of 18 September 2000 on the protection of workers from risks related to exposure to biological agents at work (EU, 2020). The basic tool of COVID-19 infection is the transmission chain between the reservoirs, the source of infection, and the host (including health and non-healthcare workers) (Kelvin and Halperin, 2020). Avoidance will focus on transmission dynamics and cutting one or several links in the transmission chain. Infection at the workplace can occur via different sources like using shared office tools (copying machines, whiteboards, pens, rollers, etc.) (Gibbins and MacMahon, 2015). According to the workplace, both hazard and exposure potential to COVID-19 will significantly differ (Rocklöv and Sjödin, 2020). For instance, the hazards and potential of exposure will be maximum in hospitals and airports.

The Failure Mode and Effects Analysis (FMEA) application to different workplaces

The governmental organizations, business owners, and employees are responsible for deciding the required actions to continually monitor and adapt the risk management framework to address exterior and interior risks. For many years, FMEA was used as a tool for risk assessment in many fields and recently used in clinical, healthcare, and clinical fields (Bonfant et al., 2010; Liu et al., 2018). To simplify the FMEA, the risk assessment can be conducted using the FMEA procedure that assigns a numerical value to each risk associated with failure.

A 5-points rating system to evaluate the following 3 categories; severity "S", occurrence "O" and the ability for detection "D" of each failure was rated (Table 1), which was modified by Duwe et al. (2005) to highlight reasonability in the simplest way to avoid confusion in evaluation, also to have accurate risk priority number (RPN) grade evaluation to be able to take the necessary control measures. The risk priority number "RPN" was then obtained by multiplying the assigned numerical values of the 3 evaluated risks "RPN= S x O x D" (Duwe et al., 2005) as shown in Table 2.

Mitigation measures of COVID-19 pandemic

To reduce the potential risks of COVID-19 in various workplaces, preparedness and response plans must be applied to control the transmission of infection between individuals and subsequently reduce the impact on the business (Bruinen de Bruin et al., 2020; Ebrahim et al., 2020).

COVID-19 preparedness and response plans

To assure that all the foremost necessary measures to control the infection in workplaces are applied, guidance must be developed by both labor and health agencies (Carinci, 2020; Koonin, 2020; Watkins, 2020). The prepared plans should consider and address the level(s) of risk of exposure to COVID-19 infection associated with various work sites and job tasks. For instance, the worker's individuals with high risk associated with age, pregnancy, or immunocompromising factors need to be addressed (Gilbert et al., 2020; WHO, 2020a). Preparedness should include three main preventive measures; basic preventive measures, prompt identification and isolation of infected persons, and increased workplace flexibilities and protection.

The basic preventive measures include strict personnel hygienic measures, social hygienic measures (e.g., social distancing), education of the public for the

Table 1: Disease severity, occurrence, and detection rating scale of COVID-19.

Weight	Severity	Occurrence	Detection
1	No symptoms	<1 in 500,000	Can be detected in the time of adequate intervention
2	Light symptoms	1 in 5000	High chance to be detected in the time of adequate intervention
3	Moderate symptoms	1 in 500	Low chance to be detected in the time of adequate intervention
4	High symptoms	1 in 50	Remote chance to be detected in the time of adequate intervention
5	Very high/Death	1 in 5	Cannot be detected

best personnel and hygienic social practices, and frequent cleaning and disinfection of workplaces appropriately using the United States Environmental Protection Agency (US EPA) approved disinfectants (Abel and McQueen, 2020; Adhikari et al., 2020; Fathizadeh et al., 2020). Of utmost importance, the plan should include the identification and appropriate isolation of infected people. For example, encouraging the employees to be aware of self-monitoring for symptoms of COVID-19, isolating themselves, or even reporting potential contact to COVID-19 suspected cases. However, this is not well applied, especially in developing and poor countries (Fathizadeh et al., 2020).

Additionally, the restrictions being applied on COVID-19 testing (i.e., not allowed by the private sector in many countries) are limiting the monitoring of COVID-19 spread and probably conceal the numbers of reported new cases (Fanidi et al., 2020; Hopman et al., 2020; Kapata et al., 2020; Koo et al., 2020; Ling et al., 2020). The workplace policy needs to include specific isolation rooms until relocating suspected persons to specialized healthcare places. However, restricting the entry to isolation rooms to well-trained persons with appropriate PPE is critical, considering the need for technical team training on the best practices in such situations (Rahimi and Talebi Bezmin Abadi, 2020; Tang et al., 2020). Likewise, increasing workplace flexibilities and protections via ensuring risk-based non-punitive leave policies are consistent with public health guidance. Moreover, reducing the number of workforce occupancy in workplaces and supporting work from home are widely applied. Unfortunately, in the developing countries, these flexibilities are not always possible due to three main causes; the dependence of workplaces on a large number of workers (manual processes), poverty levels and temporary or daily employment systems requiring daily work, and finally, the lack of the necessary infrastructure and training for home-based work (Ling et al., 2020; WHO, 2020c; Yelin et al., 2020).

Selection of control measures with special focus on healthcare workplaces

The infectious agents' controls hierarchy includes engineering controls, administrative controls, safe workplace practices, and PPE. Addressing these controls in workplaces other than healthcare places, especially to control COVID-19 spread, is not an easy process considering the limited time to achieve such measures (Berger et al., 2020; WHO, 2020b). However, achieving some level of these measures probably can help in minimizing the spread of the infection. For instance, engineering controls may include but are not limited to improving ventilation, increasing physical barriers between workers and between workers and clients. In addition, the top management decisions to change the work policy also are important as administrative control measures that may include establishing alternative days or extra work shifts, encouraging work from home, and training workers, and providing up to date information about COVID-19 (Bruinen de Bruin et al., 2020; Ebrahim et al., 2020; Lee et al., 2020; Yen et al., 2020a,b). Different workplace risk groups, risk factors, and the main engineering and administrative control measures proposed for COVID-19 according to the WHO (WHO, 2020b) are summarized in Table 3.

Nosocomial COVID-19 infections are a big problem facing all healthcare providers; therefore, implementing restrictive mitigation measures by applying the infection control hierarchy principle is needed (Cheng et al., 2020; Ochoa-Leite et al., 2021). First of all, enhancement of ventilation systems efficacy by addition of "High-Efficiency Particulate Air (HEPA)" filters on inlet and exhaust of contaminated rooms (Lynch and Goring, 2020; Azimuddin et al., 2020). Intensive care units (ICU) must be upgraded to be of the same biological containment features of negative pressure AIIR (Wong et al., 2020). The recommendations and strategic actions of the WHO to surge the hospital's capacity are needed on the administrative level. These involve a comprehensive approach linking the 4 S's of surge capacity (Space; to be expanded for COVID-19 patients, Staff; to be identified to meet expanded capacity demands, Supplies; adequate supplies to be ensured, and Systems; via establishing systems to manage and align policies to meet the surge in demand).

Table 2: The risk priority number "RPN" of COVID-19 infection in workplaces.

Activity	**Risk analysis**				**RPN interpretation**
	Severity (S)	Occurrence (O)	Detection (D)	RPN= (S*O*D)	
1. Non-healthcare workplaces					
Shared tools (Fingerprint machine, fax, copying machine, phones, etc.)	5	5	5	125	Very high
Doors lockers, elevator buttons	5	5	5	125	Very high
Gowning rooms	5	5	5	125	Very high
Contact with infected cases	5	5	5	125	Very high
Liquid waste treatment	5	5	5	125	Very high
Travelling to/from pandemic area	5	5	5	125	Very high
Authorized person to enter all areas	5	5	5	125	Very high
Shared services (toilets, restaurant, meeting rooms, etc.)	5	4	5	100	High
Solid waste handling	5	4	5	100	High
Working in goods delivery	5	4	5	100	High
Using public transportation	5	4	4	80	High
Check hands	5	4	4	80	High
2. Healthcare workplaces					
Using public transportation	5	5	5	125	Very high
Check hands	5	5	5	125	Very high
Shared medical devices (trolleys, blood pressure devices, thermometers, surgical tools, ECG., etc.)	5	5	5	125	Very high
Shared office tools (Fingerprint machine, fax, copying machine, telephones. etc.)	5	5	5	125	Very high
Doors lockers, elevator buttons	5	5	5	125	Very high
Gowning rooms	5	5	5	125	Very high
Shared services (toilets, restaurant, meeting rooms, workspace. etc.)	5	5	5	125	Very high
Infected cases isolation units	5	5	5	125	Very high
Intensive care unit (ICU)	5	5	5	125	Very high
Solid waste handling	5	5	5	125	Very high
Liquid waste treatment	5	5	5	125	Very high
Authorized person to enter all areas	5	5	5	125	Very high
Visitors/ External workforce/ sub-contractors	5	5	5	125	Very high
Dealing with asymptomatic carriers	5	5	4	100	high
Suspected cases isolation units	5	4	5	100	High
Patient sampling units and laboratories	5	4	4	80	High
Dealing with COVID-19 death cases	5	4	4	80	High
Other patients' units	5	3	5	75	Moderate
Administrative and supporting teams (security, restaurants, pharmacies)	5	3	5	75	Moderate

Table 3: Workplaces risk groups, risk factors, and the main engineering and administrative control measures for COVID-19 in different groups (WHO, 2020b)

	Example	**Risk factors**	**Engineering controls**	**Administrative controls**
Very high risk	- Healthcare workers - Healthcare or laboratory personnel	- Performing aerosol-generating procedures (e.g., intubation, or invasive specimen collection) on known or suspected COVID-19 patients. - Collecting or handling specimens from known or suspected COVID-19 patients. - Aerosol-generating procedures, on known or suspected COVID-19 dead bodies.	1. Ensure appropriate air-handling systems installation and maintenance in healthcare facilities. 2. Patients with known or suspected COVID-19 should be placed in an AIIR. 3. Using isolation rooms for performing aerosol-generating procedures on patients with known or suspected COVID-19.	1. Implementation of policies to reduce exposure (e.g. cohorting COVID-19 patients when single rooms are not available). 2. Posting of advisory signs (e.g. patients and family members to immediately report symptoms of respiratory illness and use disposable face masks). 3. Offering enhanced medical monitoring of workers during COVID-19 outbreaks.
High Risk	- Healthcare support staff - Medical transport workers - Funeral parlor workers	- Exposure to known or suspected COVID-19 patients. - Moving known or suspected COVID-19 patients in enclosed vehicles. - Funerals of people who are known to have, or suspected of having COVID-19.	4.Use special precautions associated with Biosafety Level 3 when handling specimens from known or suspected COVID-19 patients.	4. Provide all workers with job-specific education and training. 5. Ensuring psychological and behavioral support is available for employees.
Medium risk	Workers have contact with the public (e.g., schools, high-population-density work environments, high-volume retail settings).	Frequent and/or close contact with (i.e., within 6 feet of) people who may be infected with COVID-19, but who are not known or suspected COVID-19 patients	Installation of physical barriers, such as clear plastic sneeze guards, where feasible.	1. Offering face masks to all employees and customers. 2. Keeping customers informed about symptoms of COVID-19. 3. Limiting or restricting customers' and the public's access to the worksite. 4. Applying strategies to minimize face-to-face contact (e.g., drive-through windows and telework). 5. If available, on-site medical screening and care (e.g., on-site nurse; telemedicine service).
Low risk	Workers in this category have minimal occupational contact with the public and other coworkers.	No contact with people known to be, or suspected of being, infected with COVID-19 nor frequent close contact with the public. (i.e., within 6 feet of)	Not Required	Monitor public health communications about COVID-19 recommendations

Safe work practices must be enhanced specifically for infection control measures during various activities with suspected or confirmed cases, samples, material, and waste. Special care should be implemented while performing any aerosol-generating procedures such as intubation, extubation, and related procedures (Asadi et al., 2020; Tseng and Lai, 2020; Irons et al., 2021). The PPE that fits the nature of work is required (Yu et al., 2020). For instance, PPE, including long-sleeved disposable fluid repellent gowns, higher protection masks such as N95/FFP3 masks, full-face shields, or visor and gloves, are required for sampling from suspected or confirmed COVID-19 cases (Ağalar and Öztürk Engin, 2020).

Conclusion and recommendations

In our study, we go through the COVID-19 virus's epidemiological characteristics, as well as its source, persistence, and transmission dynamics. The FMEA method was used to evaluate the hazards of COVID-19 infection in various workplaces. COVID-19 infection risks are higher in healthcare workplaces than in non-healthcare workplaces, according to this study. The COVID-19 transmission risk should be reduced both conceptually and practically by implementing the best sanitary standards. As a result, it will have a good impact on the global control of COVID-19 transmission.

Additionally, many factors, including contact with health care workers caring for COVID-19 patients and contact with patients diagnosed positive for SARS-CoV-2 virus infection, can affect the spread of COVID-19 and increase the risk of transmission and the number of infected cases. Our review provides safe work practices which must be explicitly enhanced for infection control measures during various activities with suspected or confirmed cases, samples, material, and waste. Finally, it is recommended to repeat the COVID-19 infection risk assessment from time to time, especially after vaccines availability worldwide.

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