



Factors Affecting COVID-19 Transmission and Modelling of Close Contact Tracing Strategies

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Abstract

Background: Close contact tracing is an essential measure that countries are applying to combat the epidemic of COVID-19. The purpose of contact tracing is to rapidly identify potentially infected individuals and prevent further spread of the disease. In this study, based on the factors affecting the COVID-19 transmission, a scoring protocol is provided for close contact tracing.

Methods: First, the factors affecting the COVID-19 transmission in close contacts were identified by a rapid review of the literature. Data were gathered by searching the Embase, PubMed, Google Scholar, and Scopus databases. Then, by formulating and scoring the identified factors with two sessions of the expert panel, close contact transmission risk score determined, and a protocol for contacts tracing was designed.

Results: Close contact transmission risk depends on the contact environment characteristics, the infectivity (virus shedding) of the sentinel case, and contact characteristics. Based on these factors, the close contact transmission risk score and contact tracing protocol were prepared.

Conclusion: The close contact transmission risk scores will provide the ability to contact classifications and developing specific tracing strategies for them. Given that there are not any specific treatments for COVID-19 and lack of universal vaccination, applying nonpharmaceutical measures such as contact tracing along with physical distancing is very crucial. Therefore, we recommended this model to the evaluation of exposure risk and contact tracing.

Keywords: COVID-19; Transmission; Close contact tracing; Protocol

Introduction

Coronavirus disease 2019 (COVID-19) was first identified in Dec 2019 in Wuhan, China, then spreads rapidly around the world. The COVID-19 primarily spreads between people during close contact, most often via small droplets produced by coughing, sneezing, and talking (1). Therefore, the countries considered close contact tracing of COVID-19 cases as one of the first and most

important measures to the control of the disease. Close contact tracing is a public health response to the outbreak of infectious diseases, especially in the early stages of the outbreak, when specific treatments are limited (2).

Contact tracing is an effective and efficient strategy for identifying potentially infected individuals before the onset of severe symptoms. It ensures



rapid care of the patients, limits further transmission of the disease, and enables a better understanding of the transmission risk factors (2, 3). According to the WHO, close contact of a COVID-19 case is any person who had contact (within 1 meter) with a confirmed case during their symptomatic period, including 4 days before symptom onset (4). In another definition by European Centre for Disease Prevention and Control (ECDC), close contact is any person who had contact with a COVID-19 case within a timeframe ranging from 48 h before the onset of symptoms to 14 days after the onset of symptoms (5).

In close contacts, the COVID-19 transmission and exposure risk depends on many factors including route of disease transmission, patient characteristics, and environmental characteristics (6). Viruses can be transmitted from person to person through direct or indirect contact, coarse or small droplets, or contaminated objects (7). Determining the level of exposure in each contact (high-risk or low-risk exposure) is based on the associated risk of infection that in turn determines the type of monitoring and management of contacts (5). Therefore, in contact tracing, factors affecting transmission must be carefully considered and, an appropriate intervention strategy based on the evaluation of exposure risk should be selected. As well as, close contacts tracing is very costly and time-consuming when the disease is widespread in the community. Hence, having an accurate protocol for high-risk contacts tracing will be important.

Therefore, the aim of this study was modeling of close contacts tracing protocol by considering the factors affecting the COVID-19 transmission in close contacts.

Methods

We modeled the close contact tracing protocol based on factors affecting on COVID-19 transmission. The study was conducted in two general steps. In the first step, the factors affecting on COVID-19 transmission in close contact were

identified by a rapid review of literature. This review was conducted on studies published between 2019 and 2020. The search strategy conducted using keywords “contact tracing”, “close contact”, “contact”, “transmission”, “exposure”, “expose”, “coronavirus”, “COVID-19”, “novel coronavirus”, “2019-nCoV”, “severe acute respiratory syndrome coronavirus 2” and “SARS-CoV-2” across electronic databases of Embase, PubMed, Scholar and Scopus. The inclusion criteria were those papers that pointed to the characteristics of close contacts, the pattern of transmission, and factors affecting COVID-19 transmission. Papers in languages other than English were excluded (except for papers with English abstracts that had useful information). Two assessors evaluated the papers independently. Disagreements between assessors were resolved by consensus or by the decision of a third independent assessor. Computer software for reference management (Endnote X9) was used for organizing the papers. After removal of duplicate records, papers with non-relevant titles were excluded, and then, the abstract and the full text of papers were reviewed. Data analysis was done manually, and the results were categorized by content analysis method.

In the second step, we built the COVID-19 contacts tracing protocol by formulating and scoring the identified factors. In this step, to determine the COVID-19 transmission risk at close contacts, we considered a specific score for influential factors based on their characteristics. Finally, the close contact transmission risk score calculates through the sum of these scores. The protocol was developed through two expert panels. The panel members (10 experts) consisted of various specialties, including public health experts, epidemiologists, physicians, and health policy specialists. In the first panel, the research team explained the goals of the study and provided their findings and initial scoring model to the members. Based on the literature review results in the first step and the opinion of experts, the factors were prioritized in terms of their importance and effects on disease transmission, and according to the situation of each factor in differ-

ent conditions, scoring was done contractually (between 7-90 in three identified categories). In other words, the situations of the factors in each category were compared in pairs in terms of transmission risk and each situation was scored according to its risk by the consensus of experts. The first session ended with the gathering of comments and feedback from the members after 8 hours. After applying the members' comments and modifying the scoring model, the second panel was held with the presence of all members that mentioned above, and after 4 h of discussion and testing the scoring system with several cases,

the final protocol was approved by the members' consensus.

Results

From initially 6,168 studies, after removing duplicates and two-stage screening, 24 studies were eligible for the review. The results of the review showed that the risk of COVID-19 transmission from sentinel case to close contacts depends on three categories of factors: Characteristics of Contact Environment, Infectivity (Virus Shedding) of Sentinel Case, and Close Contacts Characteristics (Table 1).

Table 1: Factors affecting COVID-19 transmission from sentinel case to close contacts

<i>Category</i>	<i>Factors</i>	<i>Details</i>
Contact Environment Characteristics	Space volume of contact place	-location of the contact or exposure (6, 8) -Exposed spaces (9) -Building environment; Including buildings, cars, public transports, and other human-built spaces (10)
	Presence time of sentinel case ventilation	-Contact time; prolonged or short exposure (8, 11, 12) -Ventilation; removal of the virus-laden droplets from indoor air by ventilation (13) -Natural airflow patterns, mechanical airflow patterns, or other sources of turbulence in the indoor environment (10)
	mobility	-Movement of asymptomatic and potential infected cases (10, 14)
	Crowdedness	-Density of population (14) -The occupant density in buildings (10)
Infectivity (Virus Shedding) of Sentinel Case	Stage of infection (viral activity in the respiratory tract)	- Virus Shedding before, during, and after developing symptoms (7, 10, 15-17) - Clinical manifestations (9) - Infectious period and disease phase (18, 19)
	Droplet shedding	- Viruses can be transmitted from person to person through droplets released by an infected person through talking, coughing or sneezing (7, 10, 13, 20, 21)
Close Contacts Characteristics	Observance of safety measures	Minimizing the risk of exposure by use of face masks; covering coughs and sneezes with tissues (20)
	Contact experience	-Direct or indirect contact through: human fluids, contaminated instruments, (7) physical or individual contact (8) coarse or small droplets (7, 13) oral mucosa (22) fomites (23) environmental surfaces (7, 24, 25) -Airborne; through virus aerosols (7, 8, 25, 26) - Frequency of contact (prolonged or frequent or short) (12) - Distance of contact (27)
	Protective behavior	-Using personal protective equipment/ wearing respiratory protection e.g. N95, Surgical, of FFP1 Masks (12, 20, 24, 28-30) -Adherence to basic standard hygiene (8)
	Immune system	- Low immune function (20) -Immunosuppression (11)

The close contact transmission risk varies based on the factors' characteristics and conditions. In other words, the close contact transmission risk depends on the contact environment risk, infectivity (viral shedding) of sentinel case, and close contact risk. The following is the modeling of close contact transmission risk and tracing protocol.

Contact environment characteristics

Several studies have suggested the effect of contact environment characteristics in the risk of the

COVID-19 transmission in close contact (6, 8-13). Based on these characteristics, we determined the Contact Environment Risk Score (CERS). CERS depends on five factors: space volume of contact place, presence time of sentinel case, ventilation, mobility, and crowdedness. The space volume of contact place is an important factor in the COVID-19 transmission (10). According to Fig. 1, that shows contact environment risk score (CERS: 7-30), the appropriate space volume considered for different contact place.

Space Volume	Examples	Mean Presence Time / Day						
		< 5 min	5-20 min	20-60 min	1-2 hrs	2-5 hrs	5-10 hrs	>10 hrs
< 15 m ³	Car, Van, Elevator, WC	15	16	17	18	19	20	21
15 – 50 m ³	Autobus, Small office room	14	15	16	17	18	19	20
50 – 100 m ³	Large Offices, Classroom	13	14	15	16	17	18	19
100 – 500 m ³	House, Meeting Room, Airplane, Praying Room	12	13	14	15	16	17	18
500 – 1,000 m ³	Restaurant, Supermarket, Bank	11	12	13	14	15	16	17
1,000 – 5,000 m ³	Mosque, Cinema	10	11	12	13	14	15	16
5,000 – 10,000 m ³	Conference Hall, Gym, Small Production Units	9	10	11	12	13	14	15
> 10,000 m ³ Indoor	Department Store, Factories	8	9	10	11	12	13	14
Outdoor	ATM, Bus Station, Park	7	8	9	10	11	12	13

Add 3 point for each of following characteristics:

- Poor Ventilation
- High Mobility
- Crowdedness

Fig. 1: Contact Environment Risk Score (CERS: 7-30)

The space volume is considered to be from less than 15 m³ such as space of car, van, WC to more than 10,000 m³, such as department store, factories, and outdoor space. Contact duration in these spaces will create different risks of transmission. Therefore, we considered the presence time of sentinel case in contact from less than 5 min to more than 10 hours. By connecting contact duration with different volumes of space, we calculated the contact environment risk score from 7 to 21 (see Fig. 1). The different situations of the factors were compared in pairs with each other in terms of transmission risk, and then according to each situation risk (from low to high), scoring was done contractually between 7 to 21. In addition, poor ventilation, high mobility and crowdedness increased the CERS. Higher occupant density and increased indoor activity typically increase direct contact between individuals. High mobility in spaces with poor ventilation increases the risk of transmission (10). If any of these characteristics were present, 3 points will be added to the CERS. Finally, the CERS graded between 7 and 30 considering the different situation of these five factors, according to Fig. 1.

Infectivity (virus shedding) of sentinel case

The infectivity of the case or virus shedding rate is another factor that affects the COVID-19 transmission in close contact. Three factors affected on the infectivity of the sentinel cases: stage of infection (viral activity in the respiratory tract) (7, 9, 10, 15, 16, 18, 19), droplet shedding (7, 10, 13, 20, 21) and observance of safety measures (20).

The disease stage determines the level of infectivity, viral activity, and viral shedding. Viral shedding begins before the appearance of the first symptoms, and viral loads decrease after symptom onset (17). If we consider three phases for the disease, including Early Infection, Pulmonary Phase, and Hyper Inflammation Phase, the rate of viral activity and infectivity in the early phase will be high and decreases in the next two phases. Furthermore, the illness severity and the inflammatory response are low in the first phase, begin to increase in the second phase, and peak in the third phase (Fig. 2. Section of disease stage).

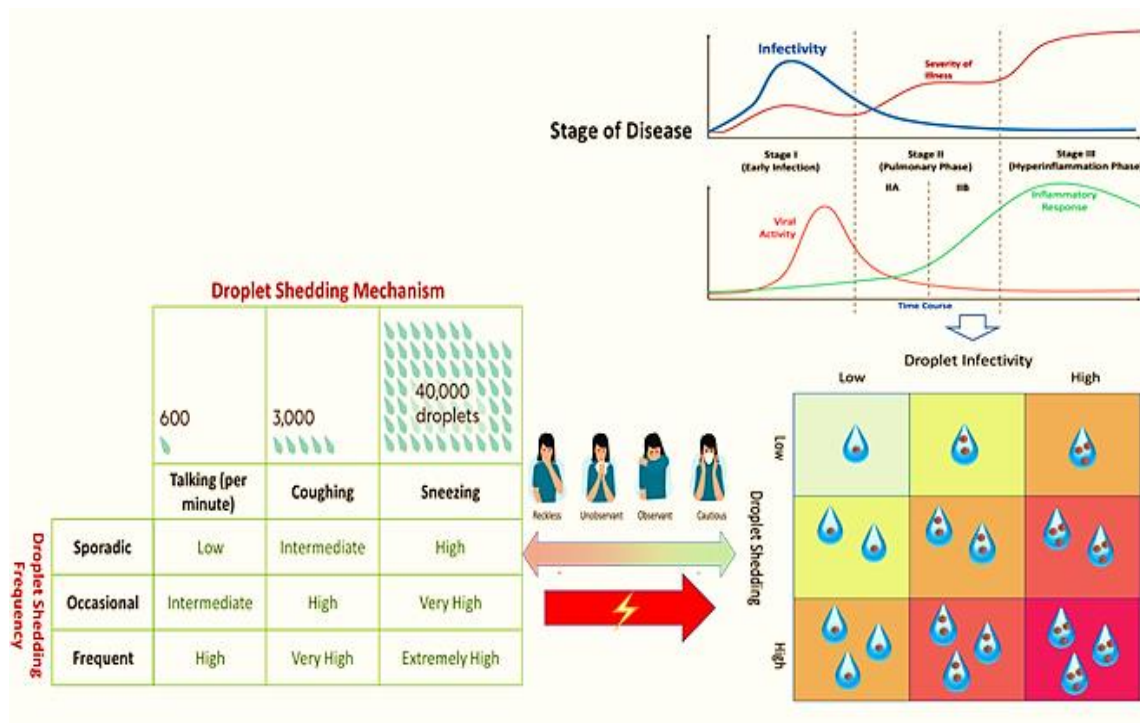


Fig. 2: Actual viral shedding by sentinel case

Currently, COVID-19 transmission through respiratory droplets has been accepted (10). Infected droplets are spread by talking, coughing, or sneezing of an infected individual. Droplet shedding status is graded, from low to extremely high, through considering the mechanism of droplet shedding (approximately 600 drops per minute through talking, 3000 drops per minute through coughing, and 40000 drops per minute through sneezing) and the frequency of droplet shedding (sporadic, occasional, and frequent). (Fig. 2) Observance of safety measures includes the use of face masks; covering coughs and sneezes with tissues can minimize the droplet shedding and risk of exposure. (Fig. 2) (20). According to the levels of safety measures observance, a sentinel case can be cautious, observant, unobservant, or

reckless. Depending on the stage of the disease and droplet shedding mechanism, the infectivity of the droplets will be different. So that, the infectivity of droplets in the pre-clinical period and the hyper inflammation Phase is low, which is moderate in the pulmonary phase and high in early infection (Fig. 2).

Based on these characteristics and by pairwise comparison of situations in terms of transmission risk, we determined the Infectivity Score of Sentinel Case (ISSC: 0-30). In Fig. 3, ISSC is calculated for unobservant sentinel cases. Add additional 5 scores for reckless cases. Subtract 2 scores for observant cases. Subtract 5 scores for cautious cases.

	Pre-clinical Period & Hyperinflammation Phase	Pulmonary Phase	Early Infection
	Low Droplet Infectivity	Intermediate Droplet Infectivity	High Droplet Infectivity
Low Droplet Shedding	5	8	12
Intermediate Droplet Shedding	8	12	15
High Droplet Shedding	12	15	18
Very High Droplet Shedding	15	18	21
Extremely High Droplet Shedding	18	21	25

Fig. 3: Infectivity score of unobservant sentinel case

Close Contacts Characteristics

Transmission risk in close contact depends on three factors: contact experience, protective behavior, and immune system performance. The contacts experience can be direct or indirect, through the particles transferred from animate or inanimate objects, or particles transferred through the air (7, 8, 12, 13, 23-26). COVID-19 transmission can occur by direct contact with sentinel case or indirect contact with surfaces or objects used on the sentinel case (31). In direct contact, where there is skin-to-skin contact between two persons, three types of contact can

occur, including intimate contact, causal contact or accidental contact. In indirect contact, where there is contact with an inanimate object that may serve as a vehicle for transmission of pathogen, depending on the contact frequency, frequent contact with shared objects or occasional contact with shared objects will occur.

The contact experience can also be through airborne particles (7, 13, 25, 26, 31). Particles transferred through the air can be large droplets, small droplet, or airborne. Confrontation with large droplets, where large droplets of 50-100 µm that travel face to face up to 2 meters, can be pro-

longed near confrontation or short near confrontation. In addition, contact experience with small droplets, where small droplets of 10-50 µm travel face to face to within the room, can be considered in two forms of prolonged distant confrontation or short distant confrontation.

Protective behaviors such as the use of personal protective equipment and wearing respiratory protection can reduce the risk of transmission in close contact (12, 20, 24, 28-30). Protective behaviors can be categorized into strict protection (e.g. use of N95, surgical, or FFP1 masks, latex gloves, disinfecting hands and working surfaces), ordinary protection (use of dust masks, polyvinyl gloves and washing hands frequently), or loose protection (following basic health recommendations).

Immune system performance is another influential factor in close contact transmission. People with weak immune systems or Immunosuppression were considered as a high-risk group (11, 20). We considered three states for the immune system: mild immunosuppression (chronic conditions: heart disease, lung disease, lupus, diabetes & malnutrition), moderate immunosuppression (in steroids, cancer), and Severe Immunosuppression (in chemotherapy, HIV/AIDS), to determine the risk of transmission in different situations.

Based on the described characteristics and by pairwise comparison of different situations in terms of transmission risk, we determined the Close Contact Risk Score (CCRS: 0-30) according to Fig. 4.

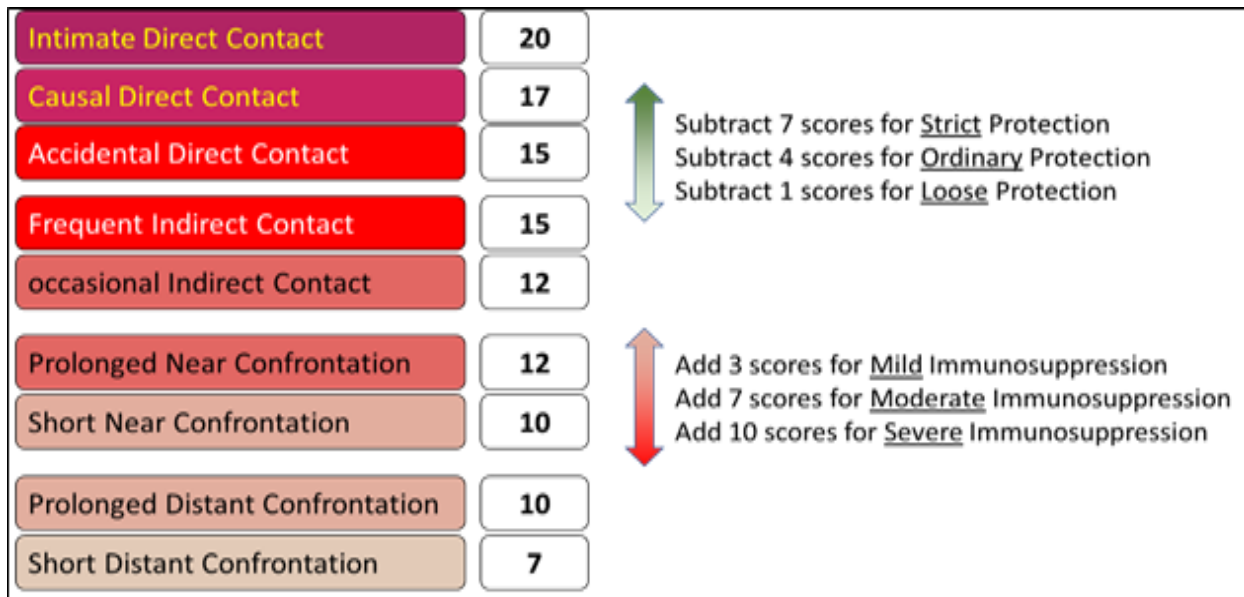


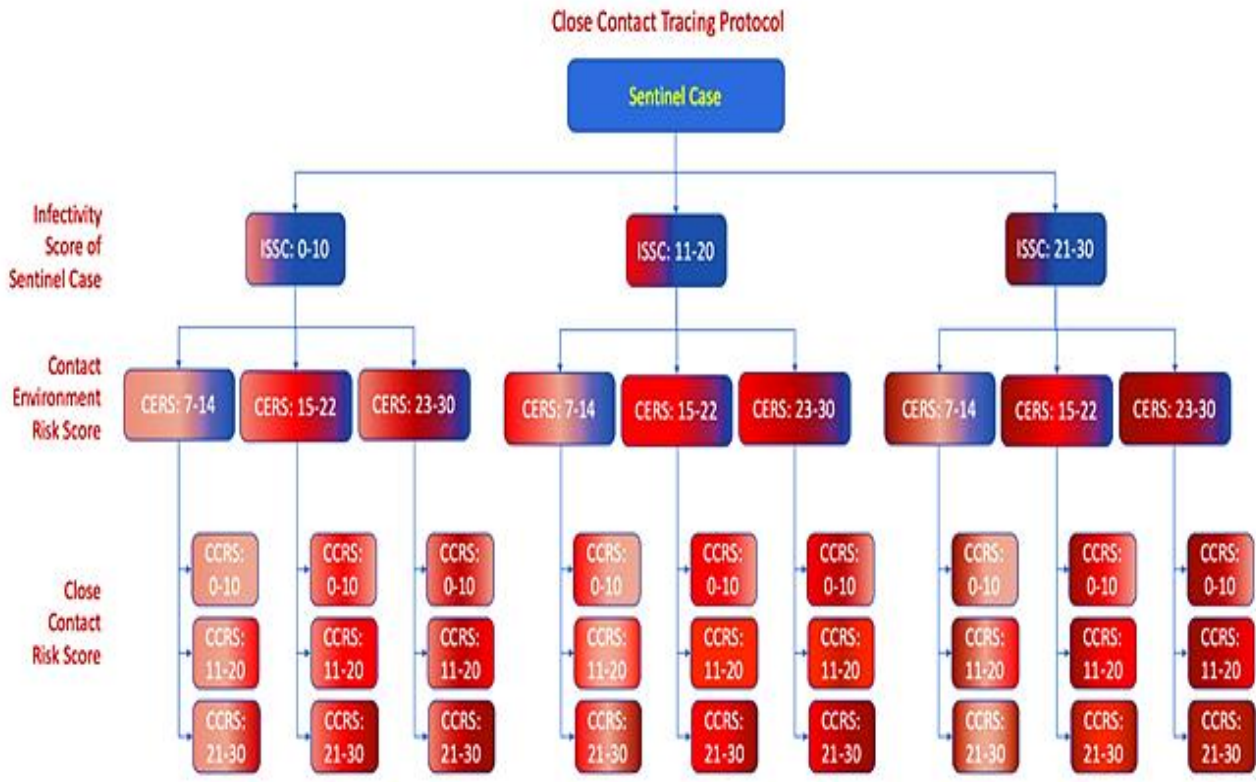
Fig. 4: Close Contact Risk Score (CCRS: 0-30)

Close Contact Transmission Risk Score (CCTRS: 7-90) and Tracing Protocol

Close Contact Transmission Risk Score (CCTRS: 7-90) is obtained through the sum of Contact Environment Risk Score (CERS: 7-30) plus Infectivity Score of Sentinel Case (ISSC: 0-30) plus Close Contact Risk Score (CCRS: 0-30).

Close contact tracing protocol is shown in Fig. 5 Based on the transmission risk scores. In this

protocol, the infectivity score of sentinel case is categorized to low risk (ISSC: 0-10), moderate risk (ISSC: 11-20) and high risk (ISSC: 21-30). Contact environment risk score and close contact risk score are also categorized to low risk (CERS: 7-14, CCTRS: 0-10), moderate risk (CERS: 15-22, CCTRS: 11-20), and high risk (CERS: 23-30, CCTRS: 21-30).



CERS: Contact Environment Risk Score (7-30)
 ISSC: Infectivity Score of Sentinel Case (0-30)
 CCRS: Close Contact Risk Score (0-30)
 CCTRS: Close Contact Transmission Risk Score (7-90)

Fig. 5: Close contact tracing protocol

According to the protocol, if the infectivity score of sentinel case were low risk (ISSC: 0-10), only high-risk contact environment (CERS: 23-30) should be traced. If the infectivity score of sentinel cases were moderate risk (ISSC: 11-20), only moderate and high-risk contact environment (CERS: 15-22, CERS: 23-30) should be traced. Finally, if the infectivity score of sentinel case were high risk (ISSC: 21-30) all contact environments should be traced.

Discussion

Since there is no definitive treatment or universal vaccination against COVID-19, the close contact

tracing is one of the most famous solutions to control its outbreak (2, 3). This approach is necessary to minimize the damage to population health and maintain economic and social activities during the pandemic (32). Generally, key steps of contact tracing include contact identification, listing and follow-up (5). Contacts tracing in the early stages of an epidemic with the limited number of patients is most effective and efficient (5). However, when the transmission has widespread in the community, it will be costly and time-consuming (33) in this regard, Keeling et al referred to the high burden and optimism of tracing all close contacts within 2 weeks (2). In addition, Hellewell et al referring to the large volume

of contact tracing to control the disease outbreak, Suggested that a 3 months effective contact tracing and case isolation could prevent a new outbreak (34). Therefore, this study aimed to present an efficient and effective protocol for close contact tracing through detecting factors affecting COVID-19 transmission.

By reviewing existed literatures on COVID-19 contact tracing different influential factors in transmission risk detected and categorized, and were organized into three general categories then a comprehensive model provides by conducting expert panels. The results of the study introduced three factors that are influential in close contact transmission risk, including the characteristics of the contact environment, the infectivity of the patient, and the contact characteristics. The contact environment risks depend on space volume of contact place, presence time of sentinel case, poor ventilation, high mobility, and crowdedness. The risk of infectivity of patients determine by stage of infection, droplet shedding, and observance of safety measures. Finally, the contact characteristics risk is associated with contact experience, protective behavior, and immune system performance.

Until now, no study has been published that calculated all these factors in a single model. For example, Covid-19 were examined transmissibility and evaluated the disease transmission risk, the results showed high transmissibility risk before and immediately after symptom onset (35). Furthermore, transmission risks of COVID-19 is most likely in prolonged unprotected exposure to a patient with symptomatic COVID-19, but there is no calculation for transmission risk (12).

Therefore, our model was applicable in identification and classification of contacts in a timely and efficient manner. The close contact tracing protocols such as the WHO (4) or ECDC protocol (5) are useful for the next steps of tracing, follow-up and contact management. In general, after evaluation of close contact transmission risk and contact identification, there are two general measures for contacts management, including: movement restriction (quarantine /isolation in-

cluding home isolation, or controlled travel) and symptom monitoring (active or passive monitoring, depending on the exposure risk) (6). Our model provided the possibility of prioritization of contact tracing cases, especially widespread transmission condition, so the limited resources can be devoted to high-risk contact exposures. Due to the limited resources, high-risk exposure contacts should be traced first.

Conclusion

In this protocol, close contact transmission risk depended on the contact environment characteristics, the infectivity of the sentinel case, and contacts characteristics. Based on the close contact transmission risk score, contacts can be classified and specific tracing strategies implemented for each.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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