Journal of Hospital Infection 106 (2020) 25–34

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Super-factors associated with transmission of occupational COVID-19 infection among healthcare staff in Wuhan, China

Y. Wang [a,1], W. Wu [b,c,1], Z. Cheng [d], X. Tan [c], Z. Yang [e], X. Zeng [f], B. Mei [g], Z. Ni [h], X. Wang [e,f,*]

[a] *Department of Infection Management, Zhongnan Hospital of Wuhan University, Wuhan, China*
[b] *School of Public Health and Management, Hubei University of Medicine, Shiyan, China*
[c] *School of Health Science, Wuhan University, Wuhan, China*
[d] *Department of Respiratory and Critical Care Medicine, Zhongnan Hospital of Wuhan University, Wuhan, China*
[e] *Department of Urology, Zhongnan Hospital of Wuhan University, Wuhan, China*
[f] *Center for Evidence-Based and Translational Medicine, Zhongnan Hospital of Wuhan University, Wuhan, China*
[g] *Department of Neurology, Zhongnan Hospital of Wuhan University, Wuhan, China*
[h] *School of Medicine, Hangzhou Normal University, Hangzhou, China*

A R T I C L E I N F O

Article history:
Received 1 April 2020
Accepted 17 June 2020
Available online 20 June 2020

Keywords:
Super-factors
Medical staff
Infection
SARS-CoV-2
Social network analysis

S U M M A R Y

Background: Globally, there have been many cases of coronavirus disease 2019 (COVID-19) among medical staff; however, the main factors associated with the infection are not well understood.
Aim: To identify the super-factors causing COVID-19 infection in medical staff in China.
Methods: A cross-sectional study was conducted between January 1st and February 30th, 2020, in which front-line members of medical staff who took part in the care and treatment of patients with COVID-19 were enrolled. Epidemiological and demographic data between infected and uninfected groups were collected and compared. Social network analysis (SNA) was used to establish socio-metric social links between influencing factors.
Findings: A total of 92 medical staff were enrolled. In all participant groups, the super-factor identified by the network was wearing a medical protective mask or surgical mask correctly (degree: 572; closeness: 25; betweenness centrality: 3.23). Touching the cheek, nose, and mouth while working was the super-factor in the infected group. This was the biggest node in the network and had the strongest influence (degree: 370; closeness: 29; betweenness centrality: 0.37). Self-protection score was the super-factor in the uninfected group but was the isolated factor in the infected group (degree: 201; closeness: 28; betweenness centrality: 5.64). For family members, the exposure history to Huanan Seafood Wholesale Market and the contact history to wild animals were two isolated nodes.

* Corresponding author. Address: Wuhan University, Zhongnan Hospital, Department of Urology, Donghu Road 169, Wuhan 430071, China. Tel.: +86-027-67812817.
E-mail address: wangxinghuan@whu.edu.cn (X. Wang).
[1] The authors contributed equally to this study.

https://doi.org/10.1016/j.jhin.2020.06.023

Conclusion: High self-protection score was the main factor that prevented medical staff from contracting COVID-19 infection. The main factor contributing to COVID-19 infections among medical staff was touching the cheek, nose, and mouth while working.

Introduction

In December 2019, a number of patients suffering from pneumonia of unknown cause were linked to a wholesale seafood market in Wuhan, China. Later, the causative agent was identified as a communicable respiratory virus of the family coronaviridae. The World Health Organization (WHO) initially named the virus as 2019 novel coronavirus (2019-nCoV) but later officially renamed it severe acute respiratory coronavirus 2 (SARS-CoV-2). On 31 January, WHO declared the resulting coronavirus disease 2019 (COVID-19) as an international public health emergency [1]. As of March 25th, 2020, the number of confirmed COVID-19 cases globally had reached 410,425, thus posing a huge global challenge to contain the virus.

Evidence of human-to-human transmission has been reported in several studies, at both hospital and community level [2–6]. However, COVID-19 infection among medical staff remains a global health concern that needs urgent intervention [7]. By February 11th, 2020, a total of 1688 medical staff in China were reported to have been infected with COVID-19 [8]. A separate study on 138 samples showed that 29% of occupation-related infections among medical staff were due to COVID-19 [9]. COVID-19 infections among healthcare providers have placed a huge physical and mental strain on the medical staff.

Assessing the cause of nosocomial, work-related COVID-19 among healthcare workers is important in reducing further loss of already stretched medical personnel. The cause of infection among these individuals may be either occupational or non-occupational. Common occupational exposure factors include loss or damage of masks, needlestick injuries and mucous membrane exposures, and tearing or damage of gloves. Common non-occupational exposure factors include gatherings, community transmission, and contact with wild animals. [10]. To date, no study has clearly outlined specific factors associated with COVID-19 among healthcare workers [8].

Usually, univariate and logistic regression analyses are used to evaluate the factors influencing transmission of diseases in a population. Although the results are credible, these methods overlook internal synergies and are not intuitive. Social network is a term derived from the social sciences, and generally refers to a group of elements and the nature and extent to which they are connected, relate, or interact between and among themselves [11]. Social networks are often presented graphically, consisting of nodes (actors) and links (ties, relations, or edges). Social network analysis (SNA) is not only a conceptual approach to social science research, but also a set of methods measuring the relationships between actors. In SNA, relationships are referred to as ties [12]. The first researches using social network analysis were conducted in the 1930s and 1940s [13,14]. With mathematical graph theory as its basis, SNA has become a multidisciplinary approach, applied in sociology, information sciences, computer sciences, geography, etc. [15]. It focuses on interconnected research mainly revolving around individual description and measurement [16]. In general, SNA aims at describing the interactions between individuals within a group as well as understanding the collective behaviour of a group [11]. In medicine, SNA has been applied in evaluating transmission of infectious diseases, bibliometric analysis, dissemination of information, and fostering co-operation among medical personnel and health institutions [17–19]. The main advantage of social network analysis method is the assessment of 'relationship' variables. This eliminates the disadvantage of using 'attribute' variables as the core factors of the research as well as withdrawing the background of the research object [11,12]. In addition, when using this method and with the help of network analysis software (e.g. Ucinet), relationships between variables can be visualized graphically.

In this study, the influencing factors were termed 'nodes' whereas the relationship between these factors was termed 'relation'. SNA was applied in this study so as to identify the 'super-factors' among infected and uninfected medical staff separately. 'Super' refers to nodes identified as having the highest degree, closeness, and betweeness in the network. 'Super-factors' are therefore at the heart of the network. In fact, besides being the core influencing factors, they are also intermediaries for other factors.

The rising trend of COVID-19 infections among healthcare providers can no longer be ignored. Surprisingly, there are currently limited studies that have explored the dynamics surrounding occupational associated COVID-19 infections among medical staff, particularly using social network analysis to graphically visualize the influencing factors for the disease. Here, we used SNA to determine 'super-factors' influencing nosocomial COVID-19 infection among medical staff and to analyse the relationship between and among these factors.

Methods

Study design and participants: government-mandated hospitals

A cross-sectional study was carried out from January 1st, to February 29th, 2020, at Zhongnan Hospital of Wuhan University. It is one of the government-mandated hospitals reserved for the treatment of COVID-19 patients in Wuhan, China. The hospital has 3200 beds and three ICU wards, with the capacity to carry out several diagnostic tests, including nucleic acid tests, and cycle threshold detection. During the study period, 187 COVID-19 patients were admitted at the hospital. Supplies for personal protective equipment (PPE) for this hospital were mainly financed by the hospital, government support, and social donation. PPE was 100% available, meaning that all medical staff had access to suitable protective equipment befitting the national quality regulations.

The research participants were enrolled using the convenience sampling method. To be included, one ought to have worked for at least 14 days since the first case of COVID-19 had been reported at the hospital. Interns and staff not directly involved in the diagnosis, examination, treatment, or care of patients, such as full-time administrators, were excluded from the study. The disease was diagnosed based on the Novel Coronavirus Pneumonia Infection (NCPI) diagnosis and treatment plan (trial version 7), issued by the National Health Commission of China [20].

Measures

To collect information from the participants, the researchers designed a self-administered questionnaire, which referred to occupational guidelines issued by the National Health Commission of China and the International Labour Organization [21,22]. The questionnaire was divided into two main sections (A and B).

Section A comprised six subsections containing questions about age, gender, occupation, years of service, infection status, and previous training on occupational protection training.

Section B contained 19 questions related to factors predisposing one to COVID-19 (see Supplementary Appendix).

Data collection procedure

The reliability and validity of the questionnaire were assessed before they were administered. The investigators explained the purpose of the study and procedures for completing the questionnaires to potential participants through telephone conversations. Upon obtaining verbal consent from eligible participants, relevant documents including a study proposal, a consent form, and a questionnaire were sent by e-mail. After completing the questionnaire, participants submitted their responses together with their electronic informed consent via e-mail. In all, 94 questionnaires (94% response rate) were filled and returned. The questionnaires were carefully reviewed; incomplete or incorrectly filled questionnaires were excluded from downstream analysis. Thus, two respondents were excluded from the survey for providing incomplete information and 92 responses were retained for further analyses.

Social network analysis

Before performing SNA, factors affecting the transmission of COVID-19 to medical staff were identified using univariate logistic regression analyses. These factors were denoted as network nodes, and they guided the correlation analyses between other factors connecting or at the edge of the network. Correlation analysis was performed to systematically analyse the relationship between indicators in the index system of critical factors. It was mainly used to construct the network analysis matrix of the critical factors for medical staff infected with COVID-19. The matrix reflects 'actor–actor' relationships, which represent the degree of connection and interaction among indicators of various influencing factors. The rows and columns of the matrix represent the critical factors, whereas the values in the matrix represent degrees of correlation between indicators.

The indicators frequently used in SNA are degree, closeness and betweenness centrality [23]. Degree is the number of friendship ties belonging to each node. Ideally it represents the number of neighbours to a node in the network [24]. The most important nodes are those that have the most ties in the network.

Closeness centrality is the sum of the distances from one node to all the other nodes. The smaller the sum, the shorter the path from one node to the rest, and the closer the node is to other nodes. It is the inverse of the average distance within a network. After normalization, the sum of the shortest distance between a node and other nodes is between 0 and 1. The larger the number, the higher the closeness centrality [23]. The normalized closeness centrality of node i is given by:

$$\textit{Closeness centrality}\ (i) = (n-1)\Big/\sum_j e_{ij},$$

where n is the number of nodes and e_{ij} is the number of links along the shortest path from node i to node j [25].

Betweenness centrality refers to the number of the shortest paths that pass through a given node [26]. Nodes with high betweenness centrality usually control information that passes between other nodes. The normalized betweenness centrality of node i is given by:

$$\textit{Betweenness centrality}\ (i) = \sum_{j,k \wedge i \neq j \neq k} \frac{g_{jik}}{g_{jk}} \Big/ \frac{(n-1)(n-2)}{2}$$

where n is the number of nodes, g_{jk} is the number of shortest paths from node j to node k, and g_{jik} is the number of shortest paths from node j to node k that pass through node i [25].

Validity and reliability of the questionnaire

The research team selected three medical staff infected with COVID-19 and three medical staff without the disease to participate in the pre-survey. The purpose and content of the pre-survey were explained and availed to the participants via e-mail. After receiving the feedback questionnaire and comments from the pilot participants, the research team addressed all contentious areas.

Statistical analysis

The mean and standard deviation (SD) were used to describe continuous variables, whereas the frequency and percentage calculated to describe categorical variables. Demographic and exposure variables between the infected and uninfected groups were compared using χ^2-test and t-test for categorical and continuous variables, respectively. SATI3.2 was used to build a co-occurrence matrix to identify and analyse critical factors associated with occupational COVID-19 among healthcare workers, whereas Ucinet 6.021 converted the data format into a co-occurrence map. Excel 2016 was used to create a database of participants. Netdraw (Version 2.118) was used to draw the co-factor network visualization map. Statistical significance was set at $P < 0.05$, and all P-values were two-sided.

Table I
Characteristics of participants

Category	All participants ($N = 92$)	Infected group ($N = 31$)	Uninfected group ($N = 61$)	OR (95% CI)	*P*-value
Gender					
Female	30 (32.61%)	21 (67.75%)	41 (67.21%)	0.894 (0.388, 2.458)	0.959
Male	62 (67.39%)	10 (32.25%)	20 (32.79%)		
Occupation					
Nurse	35 (38.04%)	17 (54.84%)	18 (29.51%)	0.038 (0.035, 0.042)	0.045
Doctor	55 (59.78%)	13 (41.94%)	42 (68.85%)		
Medicine technologist	0	0	0		
Others	2 (2.17%)	1 (3.22%)	1 (1.64%)		
Age (years)	34.39 ± 5.96	33.55 ± 5.30	34.82 ± 6.51	−1.057 (−3.959, 1.417)	0.350
Working years	10.67 ± 3.58	10.45 ± 6.08	10.79 ± 7.33	−0.867 (−0.335, 1.531)	0.827
Occupational protection training					
Yes	44 (47.83%)	19 (61.29%)	25 (40.98%)	2.28 (0.941, 5.523)	0.065
No	48 (52.17%)	12 (38.71%)	36 (59.02%)		
Contact with confirmed patients with severe symptoms					
Yes	44 (47.83%)	16 (51.61%)	28 (45.90%)	1.257 (0.529, 2.988)	0.604
No	48 (52.17%)	15 (48.39%)	33 (54.10%)		
Contact with confirmed patients with mild and micro symptoms					
Yes	49 (53.256)	20 (64.52%)	29 (47.54%)	2.006 (0.823, 4.890)	0.123
No	43 (46.74%)	11 (35.48%)	32 (52.46%)		
Transporting specimen					
Yes	17 (18.48%)	4 (12.90%)	13 (21.31%)	0.547 (0.162, 1.845)	0.326
No	75 (81.25%)	27 (87.10%)	48 (78.69%)		
Infection of medical staff in the same department					
Yes	34 (36.96%)	23 (74.19%)	11 (18.03%)	13.068 (4.638, 36.824)	0.000
No	58 (63.04%)	8 (25.81%)	50 (81.97%)		
Fever of medical staff in the same department					
Yes	38 (41.3%)	22 (70.97%)	16 (26.23%)	6.875 (2.625, 18.005)	0.000
No	54 (58.7%)	9 (29.03%)	45 (73.77%)		
Infected patients in the department					
Yes	35 (38.04%)	21 (67.74%)	14 (22.95%)	7.05 (2.697, 18.428)	0.000
No	57 (61.96%)	10 (32.26%)	47 (77.05%)		
Fever patients in the department					
Yes	48 (52.17%)	23 (74.19%)	25 (35.21%)	4.14 (1.597, 10.733)	0.003
No	44 (47.83%)	8 (25.81%)	36 (64.79%)		
Directly in charge of bed					
Yes	51 (55.43%)	17 (54.84%)	34 (55.73%)	0.964 (0.404, 2.300)	0.935
No	41 (44.57%)	14 (45.16%)	27 (44.26%)		
Single isolation ward					
Yes	42 (45.65%)	11 (35.48%)	31 (50.82%)	0.532 (0.218, 1.297)	0.163
No	50 (54.35%)	20 (64.52%)	30 (49.18%)		
Touch the cheek, especially the nose and mouth, during work					
Yes	29 (31.52%)	14 (45.16%)	15 (24.59%)	2.525 (1.010, 6.315)	0.045
No	63 (68.48%)	17 (54.84%)	46 (75.41%)		
Wear medical protective mask or surgical mask correctly					
Yes	90 (97.83%)	29 (93.55%)	61 (100%)	0.341 (0.239, 0.435)	0.045
No	2 (2.17%)	2 (6.45%)	0		
Self-protection score					
Yes	44 (47.83%)	6 (19.35%)	38 (62.30%)	0.145 (0.052, 0.407)	0.000
No	48 (52.17%)	25 (80.65%)	23 (37.70%)		
History of exposure at Huanan Seafood Wholesale Market					
Yes	0	0	0	–	–
No	92 (100%)	31 (100%)	61 (100%)		
History of contact with wild animals					
Yes	1 (1.09%)	0	1 (1.64%)	1.547 (1.308, 1.758)	0.474
No	91 (98.91%)	31 (100%)	60 (98.36%)		
Attended large parties or stayed in crowded places for 3 h or more					
Yes	6 (6.52%)	5 (16.13%)	1 (1.64%)	11.538 (1.284, 103.698)	0.008
No	86 (93.48%)	26 (83.87%)	60 (98.36%)		

Table I (*continued*)

Category	All participants ($N = 92$)	Infected group ($N = 31$)	Uninfected group ($N = 61$)	OR (95% CI)	*P*-value
Whether travelled to other cities					
Yes	2 (2.17%)	1 (3.23%)	1 (1.64%)	2.514 (0.121, 33.095)	0.622
No	90 (97.83%)	30 (96.77%)	60 (98.36%)		
Whether family members diagnosed with infection					
Yes	1 (1.09%)	0	1 (1.64%)	1.672 (1.308, 1.758)	0.474
No	91 (98.91%)	31 (100%)	60 (98.36%)		
Family members include medical staff					
Yes	32 (32.61%)	8 (25.81%)	22 (36.07%)	0.616 (0.236, 1.609)	0.321
No					
History of family members' exposure at Huanan Seafood Wholesale Market					
Yes	0	0	0	–	–
No	92 (100%)	31 (100%)	61 (100%)		

OR, odds ratio; CI, confidence interval.

Table II
Social network analysis indicators among different groups

Category	All participants			Infected participants			Non-infected participants		
	Degree	Closeness	Betweenness	Degree	Closeness	Betweenness	Degree	Closeness	Betweenness
Occupational protection training	218	26	0.23	193	29	0.37	192	30	3.01
Contact with confirmed patients with severe symptoms	306	26	0.23	172	29	0.37	40	32	0.89
Contact with confirmed patients with mild and micro symptoms	280	26	0.23	53	32	0	116	30	1.66
Transporting specimen	87	28	0.07	266	29	0.37	118	29	2.31
Infection of medical staff in the same department	401	26	0.23	276	29	0.37	34	32	0.2
Fever of medical staff in the same department	396	26	0.23	275	29	0.37	132	29	2.31
Infected patients in the department	409	26	0.23	307	29	0.37	122	30	1.34
Fever patients in the department	429	26	0.23	187	30	0.18	129	29	2.31
Directly in charge of bed	269	27	0.15	192	29	0.37	118	31	0.51
Single isolation ward	313	25	3.23	76	30	0.08	87	33	0
Touch the cheek, especially the nose and mouth, during work	97	27	0.07	370	29	0.37	122	29	4.17
Wear medical protective mask or surgical mask correctly	572	25	3.23	362	29	0.37	11	36	0
Self-protection score	558	25	3.23	0	57	0	201	28	5.64
History of exposure at Huanan Seafood Wholesale Market	0	57	0	0	57	0	191	28	5.64
History of contact with wild animals	0	57	0	49	30	0.08	0	60	0
Attended large parties or stayed in crowded places for a long time	64	27	0.07	0	57	0	0	60	0
Whether travelled to other cities	4	37	0	57	31	0	8	36	0
Whether family members diagnosed with infection	77	27	0.15	0	57	0	7	40	0
History of family members' exposure at Huanan Seafood Wholesale Market	0	57	0	125	29	0.37	14	34	0
Family members include medical staff	180	25	3.23	0	57	0	0	60	0

Ethics approval

The protocol for this was approved by the institutional ethics board of Zhongnan Hospital of Wuhan University (No. 2020036).

Results

Characteristics of the participants

In total, 92 members of medical staff participated in this study, of whom 31 (33.7%) were infected with COVID-19, whereas 61 (66.3%) were not. With regard to gender, 30 (32.61%) were females whereas 62 (67.39%) were males. The average age of the medical staff was 34 years and the average years of working was 11. Professionally, 59.7% of the participants were doctors. Among the entire staff, 47.83% had undergone training in occupational protection (Table I).

There was a significant difference between the infected and uninfected groups, with regard to the following eight factors: (i) infection of medical staff in the same department; (ii) fever of medical staff in the same department; (iii) infected patients in the department; (iv) patients with fever in the department; (v) touching the cheek, nose, and mouth during work; (vi) wearing protective medical or surgical masks correctly; (vii) self-protection score; (viii) attending large parties or staying in crowded places for three hours or more ($P < 0.05$).

Characteristics of the social networks

The social network density of infection-related factors among whole group, the infected group and the uninfected group were 0.637, 0.532 and 0.505, respectively. Detailed descriptive statistics for different groups are presented in Table II.

For all participants, wearing protective medical or surgical masks correctly (degree: 572) had the highest connection with other factors. It was the most cohesive factor ahead of self-protection (degree: 558), interaction with patients with fever in respective departments (degree: 429), patients infected with COVID-19 in the department (degree: 409), presence of medical staff infected with COVID-19 in respective department (degree: 401), and cases of fever among medical staff in the same department (degree: 396). Four factors including single isolation ward, correctly wearing protective medical or surgical masks, self-protection score, and families with a member in the healthcare field were the closest to each other than to any others. This relationship was also reflected in the central position in space (closeness: 25). The shortest path between many factors passes through a point in these four factors. Therefore, these four factors have a high mediation centrality (betweenness centrality: 3.23), acting as 'middlemen'.

In the infected group, touching the cheek, nose, and mouth while at work (degree: 370), wearing protective medical or surgical masks correctly (degree: 362), presence of infected

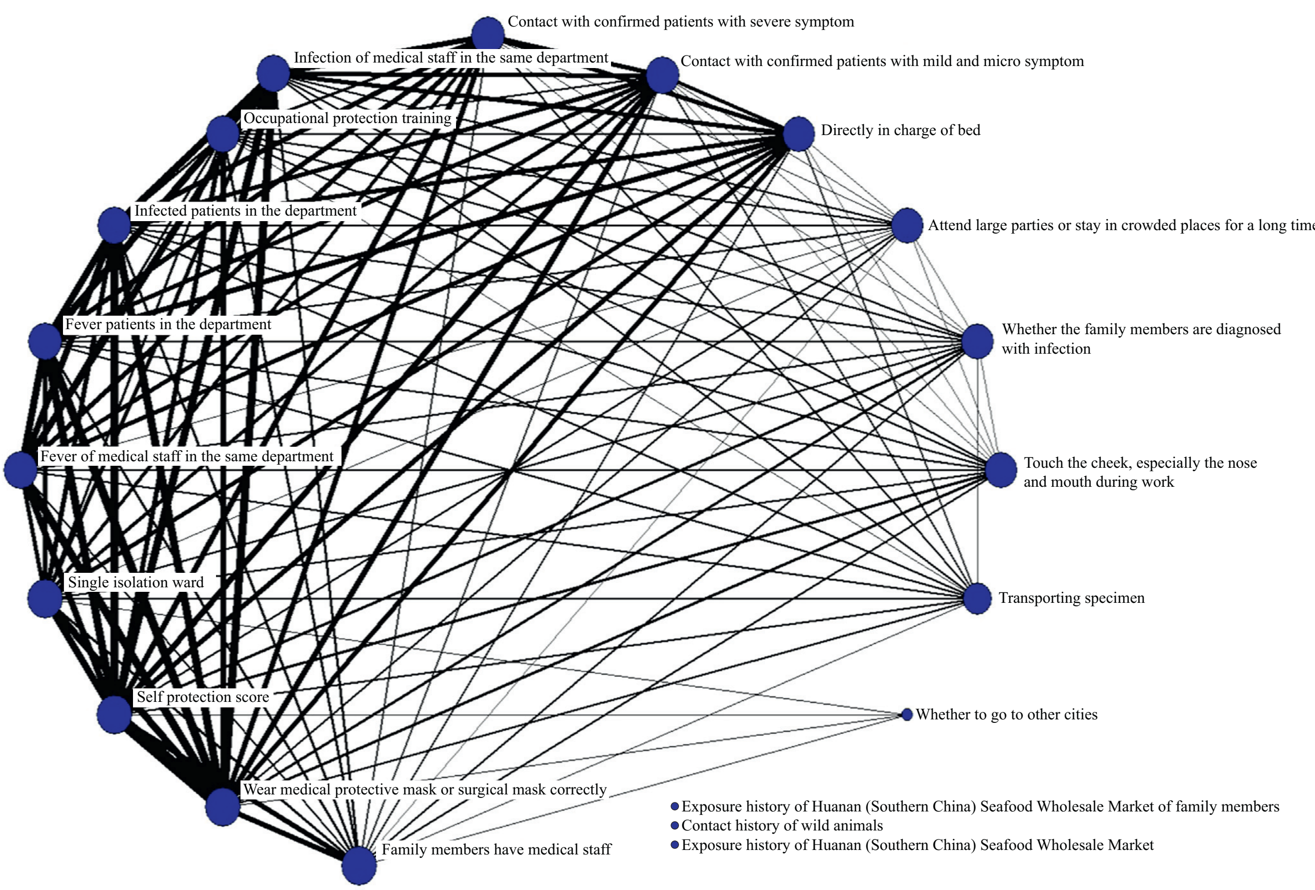

Figure 1. Visualization of social network factors among all participants. Large nodes represent higher degrees. Thickness of lines represents tier strength.

patients in the department (degree: 307), presence of infected medical staff in the same department (degree: 276), and being in the same department with a member medical staff with fever (degree: 275) had the most cohesive force. The following factors were found to have the same closeness (29) and betweenness centrality (0.37): (i) presence or absence of occupational protection training; (ii) contact with confirmed patients showing severe symptoms; (iii) transporting specimens; (iv) infection of medical staff in the same department; (v) fever in medical staff in the same department, infected patients in the department; (vi) infected patients in the department; (vii) staff directly in charge of bed; (viii) touching the cheek, nose, and mouth while working; (ix) wearing protective medical or surgical masks correctly; (x) history of exposure of family members to Huanan Wholesale Seafood Market.

For the uninfected medical staff, the self-protection score had the highest degree (201), lowest closeness (28) and highest betweenness centrality (5.64).

Comparison of networks of different groups and super-factors associated with infection

As shown in Figures 1—3, the network of all infected participants was very close whereas that of the uninfected group was further apart according to the three categories of degree, closeness, and centrality).

All participants had three isolated nodes: (i) history of contact with the Huanan Seafood Wholesale Market, (ii) history of contact with wild animals, (iii) presence of family members with history of exposure to the Huanan Seafood Wholesale Market. Both groups of infected and uninfected participants had the two same isolated nodes: (i) attended large parties or stayed longer in crowded places, (ii) one of the family members is medical health provider. However, the super-factors were different between the groups. In both groups, wearing protective medical or surgical masks correctly was the super-factor identified by the network. For the infected group, touching the cheek, nose, and mouth were found to be the super-factors associated with occupational COVID-19 while at work. It also had the largest node in the network, thus conferring the strongest influence. For the uninfected group, self-protection score was the super-factor identified by the network, whereas it was an isolated factor in the infected group.

Discussion

During the initial phase of any infectious disease outbreak, such as that of COVID-19, it is important to explore the factors influencing infection of medical staff. Here, we used SNA to analyse the relationships between such factors and to separately identify the super-factors for infected and uninfected groups. We found that not touching the cheek, nose, and mouth while working and having high self-protection score were the two super-factors that could reduce the risk of COVID-19

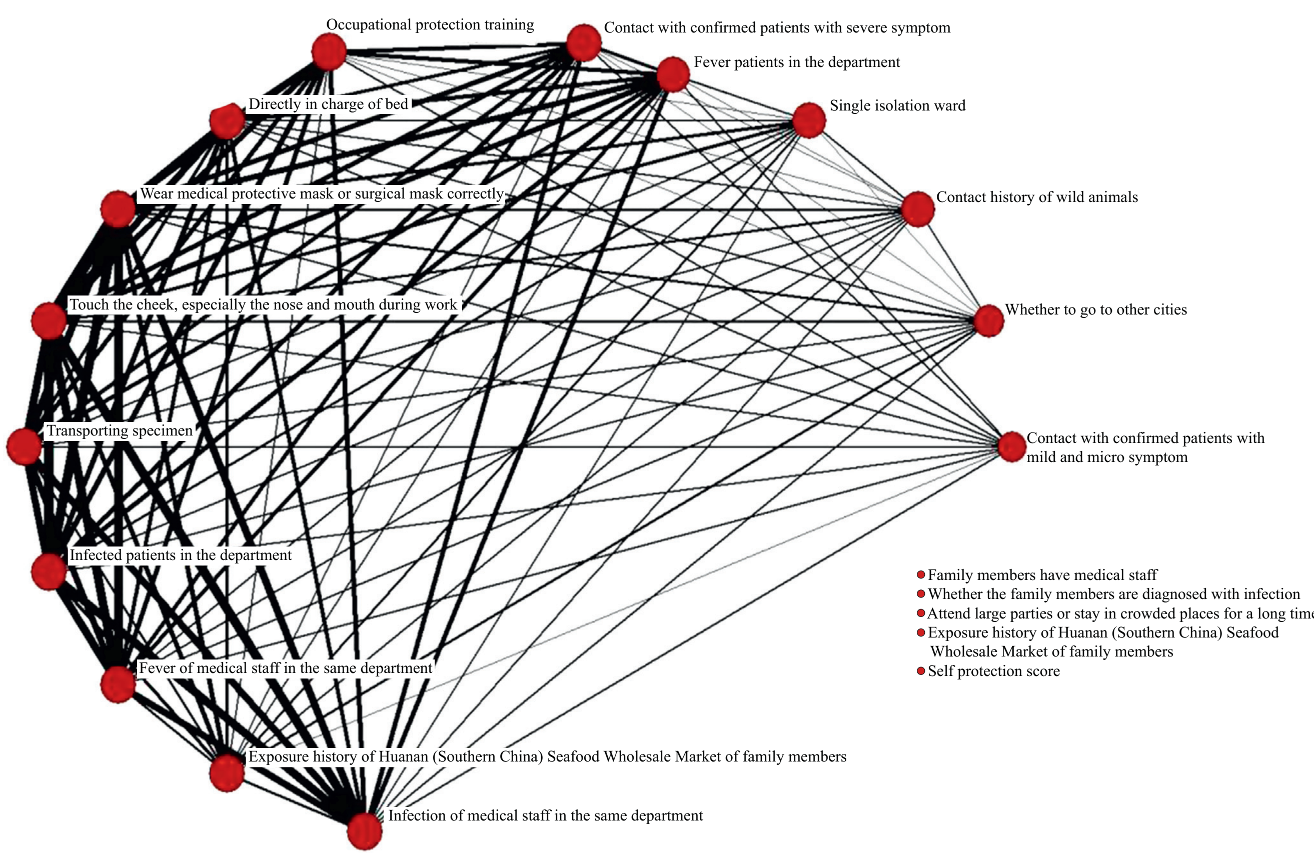

Figure 2. Visualization of social network factors among infected participants. Large nodes represent higher degrees. Thickness of lines represents tier strength.

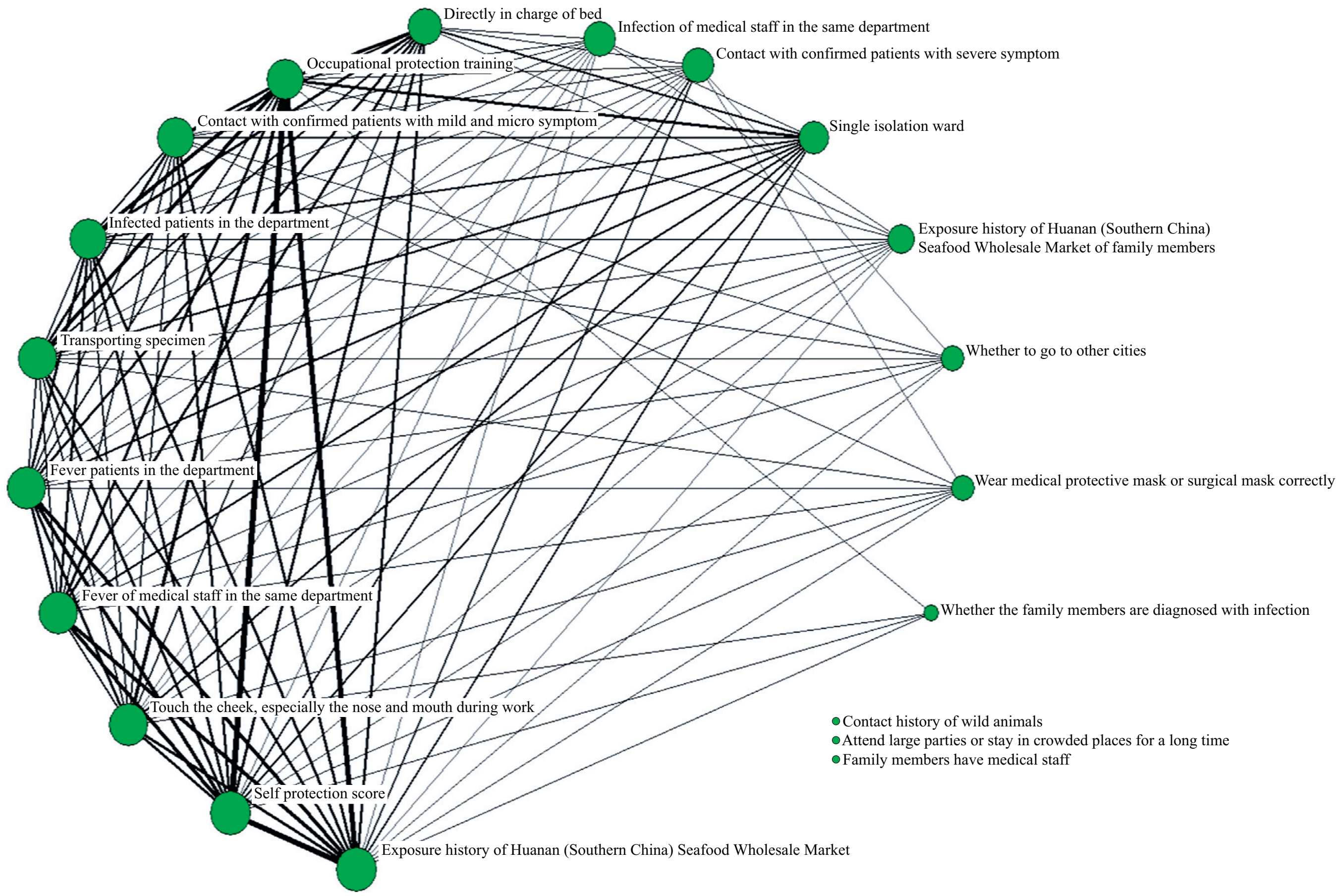

Figure 3. Visualization of social network factors among uninfected participants. Large nodes represent higher degrees. Thickness lines represents tier strength.

infection in medical staff. However, history of exposure to Huanan Seafood Wholesale Market, history of contact with wild animals, and attending large parties or staying in crowded places for three hours or more were not factors causing infection. High self-protection score means that PPE is available and used correctly. Therefore, the core factors for preventing COVID-19 infection are timely and proper use of PPE by medical staff.

The main factor leading to infection of the medical staff was touching the cheek, nose, and mouth while working. Currently, three methods have been described for COVID-19 transmission. They include direct transmission whereby droplets released by an infected person while sneezing, coughing, and talking may be directly inhaled by an uninfected person in close contact. Aerosol transmission, where droplets and aerosols from an infected person can remain airborne for long periods (where droplets shrink, forming droplet nuclei) are mixed with air to form aerosols subsequently causing the infection through inhalation. Contact transmission can occur from virus droplets deposited on surfaces of objects. This results in contamination of the hands of persons who come into contact with such contaminated surfaces. In such cases, infection occurs when contaminated hands touch the mucosa of mouth, nasal cavity, and eyes. Contact transmission can also occur when viruses are transferred from contaminated hands on to surfaces of objects. Therefore, we hypothesized that touching the mouth, nose, and eyes with contaminated hands or gloves by medical staff during work could cause infection. This emphasized the need to strengthen hand, oral, and nasal hygiene practices, especially during epidemics of respiratory infectious diseases. Following the severe acute respiratory syndrome (SARS) epidemic in 2003, there has been an increased awareness of the importance of hand hygiene among the Chinese population [27]. A study on the Middle East respiratory syndrome (MERS) epidemic indicated that hand hygiene was one of the effective measures for containing the spread of MERS [28].

The self-protection score in the network was identified as the major factor that prevented medical staff from being infected in the uninfected group. The self-protection score directly shows that the most effective measure for protecting the medical staff is PPE. Currently, WHO has given suggestions on the selection of personal protective measures for healthcare workers. The measures recommended by WHO include wearing masks — and wearing them correctly — frequent washing of hands, covering the mouth when coughing and sneezing, keeping a social distance of $\geq$1 m, and avoiding direct contact of the eyes, nose, and mouth [29]. The Chinese government has issued a series of documents to guide medical personnel on the proper use of PPE based on specific occupational risks. A published report concluded that PPE includes round hat, protective medical mask, coverall, eye protection, face protective shelter, latex gloves, barrier gown, protective clothing, shoe covers, and comprehensive respiratory apparatus. The same report proposed a checklist of the personal protection guidelines according to the area and personnel [30].

Interestingly, self-protection score was the most critical factor in the uninfected group, but was the absolute isolated factor in the infected group. This supports our hypothesis that one of the main differences between the infected and uninfected groups lies in correct and adequate self-protection. Having the right type or size of PPE and wearing it correctly is crucial to preventing COVID-19 infection. Otherwise, infection may occur via contact transmission and airborne transmission. Noteworthy, history of contact with wild animals, attending large parties, or staying in crowded places for a long time and families with medical staff were isolated nodes in three networks. A previous study showed that a history of exposure to the Huanan Seafood Wholesale Market may not be the source of the novel virus. Moreover, 13 of the 41 cases studied did not visit the marketplace [31]. Research on early transmission of COVID-19 in Wuhan suggested that although some earlier patients could have been infected through zoonotic exposures, it was evident that human-to-human transmission had occurred [2]. Avoiding large parties and not staying in crowded places for a long time were preventive measures for the public; however, these were not priority precautions for medical staff [32]. We can theorize that the infection of medical staff was due to incorrect use of PPE rather than community infection at the initial outbreak phase. During the SARS epidemic, 1706 healthcare workers were affected globally [33]. Some studies have previously reported that inappropriate or insufficient infection control measures such as inconsistent use of PPE and reuse of N95 respirators were risk factors for infection in healthcare workers [33–35]. This is similar to our study findings.

Our study has some limitations: first, the participants were enrolled from one hospital, where the sample size was insufficient; second, the data was collected in the early stage of the outbreak, so this study has not analysed the infection of medical staff throughout the whole epidemic period. Despite the sample size, our results are credible and meaningful. First, 92 front-line medical staff were recruited in government-mandated hospitals, which was a relatively large sample size and sufficiently representative in the initial phase of the COVID-19 outbreak whether in China or other countries. Second, we used the early available data on medical staff infection to carry out epidemiological investigation in the early stage of the epidemic. This will help to determine whether the infection of medical staff occurred via nosocomial infection or community infection. Third, early investigation in the initial phase of the COVID-19 outbreak avoids retrospective bias of medical staff to a certain extent, that is, to ensure the accuracy of their responses in the questionnaire.

In conclusion, touching the cheek, nose, and mouth while working increases the risk of COVID-19 infection. Wearing right type or size of PPE every time as required and following the operation specifications and operation instructions improves self-protection of medical staff against COVID-19 infection. In future studies, it will be necessary to adopt cohort studies or intervention studies to verify the role of adequate and standardized protection in preventing from COVID-19 infection.

Acknowledgements

We thank all the healthcare workers who participated in this study.

Conflict of interest statement
None declared.

Funding source
This work was supported by the Emergency Science and the Technology Project of Hubei, China (grant no. 2020FCA008).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2020.06.023

References

[1] World Health Organization. Director-General's opening remarks at the media briefing on COVID-19. 28 February 2020. Available at: https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19—28-february-2020 [last accessed February 2020].
[2] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020;382:1199–207.
[3] Chan JF, Yuan S, Kok KH, To KKW, Chu H, Yang J, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. Lancet 2020;395:514–23.
[4] Phan LT, Nguyen TV, Luong QC, Nguyen TV, Nguyen HT, Le HQ, et al. Importation and human-to-human transmission of a novel coronavirus in Vietnam. N Engl J Med 2020;382:872–4.
[5] Rothe C, Schunk M, Sothmann P, Bretzel G, Froeschl G, Wallrauch C, et al. Transmission of 2019-nCoV infection from an asymptomatic contact in Germany. N Engl J Med 2020;382:970–1.
[6] Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modeling study. Lancet 2020;395:689–97.
[7] Patel A, Jernigan DB. 2019-nCoV CDC Response Team. Initial Public Health Response and Interim Clinical Guidance for the 2019 Novel Coronavirus Outbreak – United States, December 31, 2019–February 4, 2020. Morb Mortal Wkly Rep 2020;69:140–6.
[8] Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) in China. Chin J Epidemiol 2020;41:145–51.
[9] Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA 2020;323:1061–9.
[10] Huang Z, Zhuang D, Xiong B, Deng DX, Li H, Lai W. Occupational exposure to SARS-CoV-2 in burns treatment during the COVID-19 epidemic: specific diagnosis and treatment protocol. Biomed Pharmacother 2020;127:110176.
[11] Bandyopadhyay S, Rao AR, Sinha BK. Models for social networks with statistical applications. Los Angeles: SAGE; 2011.
[12] Dempwolf CS, Lyles LW. The uses of social network analysis in planning: a review of the literature. J Plann Lit 2012;27:3–21.
[13] Moreno JL. Who shall survive? Washington, DC: Nervous and Mental Disease Publishing Company; 1934.
[14] Heider F. Attitudes and cognitive organization. J Psychol 1946;21:107–12.

[15] Otte E, Rousseau R. Social network analysis: a powerful strategy, also for the information sciences. J Inform Sci 2002;28:41.
[16] Chambers D, Wilson P, Thompson C, Harden M. Social network analysis in healthcare settings: a systematic scoping review. PLoS One 2012;7:520—1.
[17] Gundlapalli A, Ma XL, Pettey W, Greenberg R, Hales J, Benuzillo J, et al. Social network analyses of patient-healthcare worker interactions: implications for disease transmission. AMIA Annual Symposium Proceedings 2009 2009:213—7.
[18] Dalpe R. Bibliometric analysis of biotechnology. Scientometrics 2002;55:189—213.
[19] Schoen MW, Moreland-Russell S, Prewitt K, Carothers BJ. Social network analysis of public health programs to measure partnership. Soc Sci Med 2014;123:90—5.
[20] National Health Commission of the People's Republic of China, Office of National Administration of Traditional Chinese Medicine. Notice on printing pneumonia diagnosis and treatment strategy of new coronavirus infection (Trial Version 7) [in Chinese]. Available at: http://www.nhc.gov.cn/yzygj/s7653p/202003/46c9294a7dfe4cef80dc7f5912eb1989.shtml [last accessed March 2020].
[21] Health Commission of Henan Province. Notice of the general office of the National Health Commission on the issuance of technical guidelines on the protection of medical personnel during COVID-19 outbreak (trial) [EB/OL]. Available at: http://www.hnwsjsw.gov.cn/contents/859/48718.shtml [last accessed February 2020].
[22] International Labour Organization. Occupational safety and health in public health emergencies: a manual for protecting health workers and responders. Available at: http://www.ilo.org/global/topics/safety-and-health-at-work/resources-library/publications/WCMS_633233/lang-zh/index.htm [last accessed June 2020].
[23] Rabbani A, Biju NR, Rizwan A, Sarker M. Social network analysis of psychological morbidity in an urban slum of Bangladesh: a cross-sectional study based on a community census. BMJ Open 2018;8:1—29.
[24] Salamati P, Soheili F. Social network analysis of Iranian researchers in the field of violence. Chin J Traumatol 2016;19:264—70.
[25] Abbasi A, Altmann J. On the correlation between research performance and social network analysis measures applied to research collaboration networks. In: 44th Hawaii International Conference on System Sciences, Hawaii, USA, January 4th—7th, 2011; 2011.
[26] Hou H, Kretschmer H, Liu Z. The structure of scientific collaboration networks in Scientometrics. Scientometrics 2008;75:189—202.
[27] Lau TF, Yang X, Tsui H, Kim JH. Monitoring community responses to the SARS epidemic in Hong Kong: from day 10 to day 62. J Epidemiol Commun Health 2003;57:864—70.
[28] Sikkema RS, Farag EABA, Himatt S, Ibrahim AK, Al-Romaihi H, Al-Marri SA, et al. Identification of risk factors for primary MERS-CoV infection in camel workers in Qatar, 2013—2014; a case—control study. J Infect Dis 2017;215:1702—5.
[29] World Health Organization. Home care for patients with suspected novel coronavirus (nCoV) infection presenting with mild symptoms and management of contacts. 2020. Available at: https://www.who.int/publications-detail/home-care-for-patients-with-suspected-novel-coronavirus-(ncov)-infection-presenting-with-mild-symptoms-and-management-of-contacts [last accessed February 2020].
[30] Jin YH, Cai L, Cheng ZS, Cheng H, Deng T, Fan YP, et al. A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). Mil Med Res 2020;7:4.
[31] Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020;395:497—506.
[32] World Health Organization. Coronavirus disease (COVID-19) advice for the public. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public [last accessed February 2020].
[33] Low JG, Wilder-Smith A. Infectious respiratory illnesses and their impact on healthcare workers: a review. Ann Acad Med Singapore 2005;34:105—10.
[34] Ofner-Agostini M, Gravel D, McDonald LC, Lem M, Sarwal S, McGeer A, et al. Cluster of cases of severe acute respiratory syndrome among Toronto healthcare workers after implementation of infection control precautions: a case series. Infect Control Hosp Epidemiol 2006;27:473—8.
[35] Lai TS, Yu WC. The lessons of SARS in Hong Kong. Clin Med 2010;10:50—3.