Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Journal of Hospital Infection 119 (2022) 132–140

Available online at www.sciencedirect.com

Journal of Hospital Infection

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

Development and validation of a competency evaluation model for hospital infection prevention and control practitioners in the post-pandemic era: a mixed methods study

L. Cui [a], A. He [a], X. Wang [a], Y. Wang [b], X. Huang [a], Z. Ni [a,*]

[a] Department of Health Management, School of Medicine and Health Management, Hangzhou Normal University, Yuhang District, Hangzhou, Zhejiang, PR China

[b] Department of Nosocomial Infection Prevention and Control, Zhongnan Hospital of Wuhan University and Department of Nosocomial Infection Prevention and Control, Leishenshan Hospital, Wuhan, Hubei, PR China

ARTICLE INFO

Article history:
Received 27 May 2021
Accepted 25 August 2021
Available online 16 October 2021

Keywords:
COVID-19
Infection prevention and control practitioners
Competency model
Nosocomial infection

SUMMARY

Background: During the coronavirus disease 2019 pandemic, the management of nosocomial infections became even more crucial. There is an urgent need to develop a competency model for healthcare practitioners to combat public health emergencies.

Aim: To determine practitioners' competency in hospital infection prevention and control measures.

Methods: A theoretical framework was developed based on a literature review, key informant interviews, the Delphi method and a questionnaire survey. These items were evaluated based on response rate, maximum score, minimum score and mean score. Factor analyses, both exploratory and confirmatory, were used to determine the structure of the competency model.

Results: The effective response rate for the questionnaire was 88.29%, and Cronbach's α-coefficient was 0.964. Factor analysis revealed a Kaiser–Meyer–Olkin score of 0.945. Bartlett's test gave a χ^2-value of 10523.439 (df=435; $P<0.001$). After exploratory factor analysis, the five-factor model was retained, four items were deleted and a five-dimensional, 26-item scale was obtained. The new structure's confirmatory factor analysis revealed high goodness of fit (comparative fit index=0.921; Tucker–Lewis index=0.911; standardized root mean square residual=0.053; root mean square error of approximation=0.044).

Conclusion: The proposed scale is a useful tool to assess the competency of hospital infection prevention and control practitioners, which can help hospitals to improve infection prevention and control.

Introduction

Coronavirus disease 2019 (COVID-19) has had an unprecedented impact on the world since the end of 2019, and has been declared a major public health emergency by the World Health

* Corresponding author. Address: Department of Health Management, School of Medicine and Health Management, Hangzhou Normal University, No. 2318, Yuhangtang Rd, Yuhang District, Hangzhou, Zhejiang, PR China. Tel.: +86 186 7278 2182.
E-mail address: ziling@hznu.edu.cn (Z. Ni).

https://doi.org/10.1016/j.jhin.2021.08.028

Organization [1]. In addition to its global health impact, COVID-19 has alarmed the healthcare community about the danger and harm of nosocomial infections. Nosocomial infections associated with COVID-19 have been identified and reported by several healthcare facilities across the world [2]. Due to the lack of adequate awareness about COVID-19 during the early stages of the pandemic, healthcare workers were also infected [3]. An early research report on 138 cases of COVID-19 revealed that 41.3% of all cases were nosocomial infections, of which medical staff transferred 12.3% of infections [4]. Similar nosocomial infection cases have also been reported in the USA, the UK and South Korea [2]. Notably, nosocomial infections can have serious consequences. They can directly affect the quality of medical care that can be provided, and cause cross-infection. This can be detrimental to patients who are already immunocompromised, thus acting as a potential contributing factor to a secondary infection outbreak [5,6]. As such, great importance should be attached to nosocomial infections, especially in the post-pandemic period. Conducting high-quality hospital infection prevention and control measures can reduce the occurrence of severe complications and deaths, and preserve hospital functions to provide adequate care for all patients [7]. Hospital infection prevention and control practitioners (HIPCPs) play a key role in preventing and controlling nosocomial infections. Therefore, HIPCPs should have the professional knowledge and skills to manage nosocomial infections more efficiently and effectively.

Numerous regions and countries have paid attention to the competency of HIPCPs, and have constructed frameworks to measure the professional competency of HIPCPs in multiple dimensions, including North America [8–10], Europe [11], the UK [12–14], Hong Kong and China [15]. These regions and countries have proposed several preventive care dimensions, and have suggested indicators to measure competency, such as through surveillance, evidence-based practice (including occupational health), collaboration and partnership, and education, among others. These competency frameworks play a key role in recognizing and improving the level of professionalism in nosocomial infection prevention and control to ensure patient safety and the quality of healthcare provision in a certain period [15]. Moreover, their experience can prove useful for the infection management field. However, nosocomial infections have posed a serious challenge to HIPCPs during the COVID-19 pandemic, reflecting a situation wherein the previous competency model should be updated to meet the new requirements put forward by the COVID-19 pandemic [16,17]. These requirements not only address the basic skills and sufficient knowledge, but also the ability to respond to public health emergencies and information technology. In addition, HIPCPs are people with medical-related professional education. They may not have received adequate professional training in infectious disease control and prevention, and may not have sufficient experience dealing with infectious diseases and patients [18]. Thus, identifying the competency of HIPCPs is central to ensuring high-quality nosocomial infection prevention and control measures, and improving management efficiency. Scientific evaluation of the ability of HIPCPs is a necessary preliminary condition to improve nosocomial infections. Reliable, credible and valid assessments are essential to help hospital management develop targeted training, enhance the professionalism of HIPCPs, and propose effective incentives for HIPCPs. Previous studies have suggested the need for the development of tools to enhance the professionalism of HIPCPs [2,19,20].

As such, the proposal of a new model to comprehensively evaluate the competency of HIPCPs is of great significance. Hospital infection prevention and control was an important and effective part of the Chinese people's joint fight against the COVID-19 pandemic. This study was conducted in ZhongNan Hospital of Wuhan University, Leishenshan Hospital, and other major pandemic-fighting hospitals. The participants were HIPCPs who were involved in the fight against the pandemic in China. Their capabilities were investigated using a survey, and a conceptual framework has been developed and validated to evaluate the competencies of HIPCPs in the post-pandemic era.

Methods

Research design

A mixed-methods approach was adopted to develop a competency evaluation model of HIPCPs between February 2020 and November 2020. First, a literature review, key informant interviews and the Delphi method were used to form the competency framework and develop the measurement scale. Next, an online questionnaire survey was conducted in HIPCPs involved in pandemic prevention and control in COVID-19-designated hospitals, and data were collected. Subsequently, reliability and validity analysis and factor analysis were conducted to validate the scale. Finally, a scientific and practical competency model for HIPCPs was conducted. Nvivo 11 was used to record, transcribe and analyse text data from the interviews and expert consultations. SPSS 25.0 and Mplus 8.3 were employed for data analysis.

Informed consent of all subjects was sought before participation in the study.

Initial scale development

The initial HIPCP competency measurement scale was developed in three phases. Firstly, a comprehensive literature review was performed based on a competency onion model. 'Competency', 'competency framework', 'hospital infection', 'nosocomial infection', 'infection prevention practitioner' and 'COVID-19' were used as keywords to search Web of Science, PubMed, MEDLINE and China National Knowledge Infrastructure in both English and Chinese. The search period was January 2000 to May 2020. In addition, a manual search of documents on competency standards for HIPCPs was undertaken, particularly the newest guidelines for practitioners published during COVID-19. Literature and documents related to competency, skills and professional standards of HIPCPs were selected for inclusion, and those not mentioned were excluded. Next, a comprehensive review of the competency dimensions and items mentioned in the literature and documents was conducted, and a list was created. In addition, an interview outline was developed for the key informant interviews, considering the important elements of hospital infection management mentioned in the literature.

Secondly, a key informant interview was conducted with HIPCPs, the front-line practitioners at COVID-19 designated hospitals, based on the outline. The number of interviewees

was determined according to the theoretical saturation principle of grounded theory (i.e. interviews conducted until the point that no new important information was provided). Each interviewee was interviewed via telephone for 25–40 min. The interviews focused on five parts: (1) background of execution of prevention and control measures; (2) action strategy; (3) implementation plan; (4) support conditions; and (5) obstacles in execution. A three-level coding analysis of the textual interview data was employed based on grounded theory, and competency elements and vital dimensions were extracted according to the frequency and importance of content mentioned in the interviews. After that, the elements were added to the competency list.

Thirdly, three rounds of expert consultation were employed to check the validity of the content, and deletions and modifications to the dimensions and items were made. Thirteen experts from different fields were invited to form an expert group (including nosocomial infection specialists, public health experts, epidemiologists, chief of infection department, etc.) to conduct three rounds of consultation. The first round of expert consultation identified the competency dimensions. The latter two rounds deleted unsuitable items, modified some items, added some reasonable items, and adjusted the position of some items. Ultimately, the competency framework was developed and the scale was created. Each item was scored using a five-point Likert scale (1=strongly disagree, 5=strongly agree).

Data analysis

Frequencies and percentages were adopted to describe demographic data. The response rate, highest score, lowest score and average score were calculated for each item. Reliability refers to the consistency, stability and reliability of the results. Cronbach's α was used to measure internal consistency between the items. The reliability of the scale was acceptable when Cronbach's α was >0.7. Validity refers to the degree to which a measurement tool can accurately measure what is to be measured. Factor analysis was used to examine structural validity. Kaiser–Meyer–Olkin (KMO) values were calculated and Bartlett's test was performed. The closer the KMO value was to 1, the stronger the correlation between the variables and the more suitable for factor analysis. Bartlett's test determined the correlation matrix of each item. The significant result indicated a correlation between items, suggesting that it was suitable for factor analysis.

Exploratory factor analysis (EFA) was used to determine the potential factor structure of the items. Oblique rotation was used to process the data. Although the scale was initially constructed with a four-factor model, a two-to six-factor EFA analysis was conducted to enhance exploratory. A factor loading of 0.4 was selected as the item cut-off value to identify items that were closely related to a specific factor. Items with factor loadings <0.4 and a factor loading difference <0.1 were excluded. Subsequently, confirmatory factor analysis (CFA) was used to verify the goodness of fit of the factor structure. Chi-squared test of model fit (χ^2/df), Tucker–Lewis index (TLI), comparative fit index (CFI), standardized root mean square residual (SRMR) and root mean square error of approximation (RMSEA) (90% confidence interval) were selected as the evaluation index. TLI >0.90, CFI >0.90, SRMR <0.08 and RMSEA <0.05 indicated a good fit. Cronbach's α was used to test the internal consistency of potential factors. Reliability was acceptable at $\alpha >0.7$ and $P<0.05$.

Results

Results of the literature review

In total, 221 records were searched and 172 unqualified records were excluded. The 49 articles included involved competency requirements, frameworks and models for HIPCPs from researchers in North America, Northern Europe, China, the UK, Hong Kong and China. Five competency dimensions and 328 competency entries (including duplicates) were extracted from the articles and documents. After deleting the duplicate entries and summarizing those with similar meanings, a competency list of 26 items in five dimensions was formed (Table I). Moreover, the execution background, action strategy, implementation and influencing factors of hospital infection management were compiled, and an interview outline was formed for key informant interviews (Table S1, see online supplementary material).

Results of the key informant interviews

Twelve interview records were collected, and the main elements frequently mentioned by the practitioners were 'hospital infection surveillance and prevention and control capabilities', 'ability to organize and collaborate in emergencies', 'professional capacity to adapt to new situations and to

Table I
Competency dimensions and items

Dimensions	Items
Hospital infection risk predict ability	Surveillance and report
	Perfecting supervision system
	Infection identification
Hospital infection management ability	Management and control
	Rules and regulations
	Contingency planning
	Occupational health
	Health guidance
	Health education
Professional development capability	Learning skill
	Scientific research
	Occupational planning
	Information technology
	Internet plus
Organizational collaboration ability	Meeting basic needs
	Organize and conduct training
	Teamwork
	Collaboration
	Emergency organization
	Psychological counselling ability
Personal trait	Stress resistance
	Adaptability
	Dedication
	Persevere
	Decisiveness
	Responsibility

continuously enhance and develop' and 'personal traits that contribute to work'. All the dimensions in the list contained these points. Furthermore, they also mentioned some keywords that related to the subcategories in the interview outline, including 'orderly multi-department coordination', 'screening ability of protective and disinfectant products', 'building layout and its timely reconstruction' and 'effective ability training in emergencies'. Also, cases related to the implementation of informatization of hospital infection management were mentioned repeatedly. Therefore, six items were added to the competency list: 'resource coordination', 'quality control', 'layout and reconstruction of the emergency site', 'supervision and guidance', 'advanced technique skill' and 'information awareness'.

Results of the Delphi method

Experts believe that 'hospital infection risk predict ability' and 'hospital infection management ability' were both basic skills of HIPCPs. Hence, they were combined into the 'professional skill' dimension. The four dimensions were finally identified as follows: F1, 'professional skill'; F2, 'professional development capability'; F3, 'organizational collaboration ability'; and F4, 'personal trait'.

After discussion, the experts placed the new entries 'quality control', 'layout and reconstruction of the emergency site' and 'supervision and guidance' into dimension F1, 'advanced technique skill' and 'information awareness' into dimension F2, and 'resource coordination' into dimension F3. The entry 'infection identification' had been deleted due to similar meaning to 'surveillance and report'. 'Health guidance' was also deleted due to similar meaning to 'occupational health' and 'health education'. The meanings of 'information technology' and 'internet plus' were unclear, and the new entries 'advanced technique skill' and 'information awareness' were more accurate. Therefore, the two former items were deleted.

In addition, the experts felt that the item 'surveillance and report' could not reflect the specific ability requirements, and suggested that it should be divided into 'monitoring and risk assessment' and 'statistical reporting'. Furthermore, the experts found that the expression 'perfecting supervision system' was incorrect because HIPCPs did not have the power to formulate the regulations, and suggested an amendment to 'feedback and suggestions'. In addition, the experts also mentioned that the definition of 'occupational health' was not clear, and they proposed it should be divided into 'skill instruction' and 'self-protection'. The experts also pointed out that 'adaptability' and 'psychological counselling' were the developmental capacity manifested by HIPCPs in the COVID-19 pandemic. Therefore, they should be generalized in 'professional development capability'.

As a result, four items were deleted, four items were amended, two items were added, and the location of two items was adjusted. Table II presents the competency framework of 30 items in four dimensions for the HIPCPs.

Table II
Key elements for the evaluation of hospital infection prevention and control practitioners in the post-pandemic era

Dimensions	Number	Key elements
F1 Professional skill	a1	Monitoring and risk assessment
	a2	Statistical reporting
	a3	Quality control
	a4	Management and control
	a5	Layout and reconstruction of emergency site
	a6	Rules and regulations
	a7	Feedback and suggestions
	a8	Contingency planning
	a9	Supervision and guidance
	a10	Skill instruction
	a11	Self-protection
	a12	Health education
F2 Professional development capability	b1	Learning skill
	b2	Scientific research
	b3	Occupational planning
	b4	Advanced technique skill
	b5	Information awareness
	b6	Adaptability
	b7	Psychological counselling ability
F3 Organizational collaboration ability	c1	Meeting basic needs
	c2	Organize and conduct training
	c3	Resource coordination
	c4	Teamwork
	c5	Collaboration
	c6	Emergency organization
F4 Personal trait	d1	Stress resistance
	d2	Dedication
	d3	Persevere
	d4	Decisiveness
	d5	Responsibility

Respondents and questions

The survey was conducted on 461 HIPCPs from 15 provinces in China. Fifty-four invalid questionnaires with missing or incomplete feedback were excluded. The practical response rate was 88.29%. Among the respondents, 78.13% were women. One hundred and twenty-eight participants were aged 31–40 years and 151 participants were aged 41–50 years; these two age groups accounted for 68.55% of the total number of participants. In addition, 80.34% of the respondents had clinical, public health, nursing and professional education backgrounds, and those with a bachelor degree or above accounted for 65.02% of the respondents. Two hundred and forty-nine participants had middle HIPCP titles or above, accounting for 58.97% of respondents. In China, the professional designations of HIPCPs are junior (technologist), middle (technologist-in-change), deputy senior (senior associate technologist) and senior (full senior technologist). Moreover, 79.36% of respondents had participated in hospital infection management work for >5 years, of which 180 were from tertiary hospitals, 138 were from secondary hospitals, and five were from primary hospitals. The average time taken by the respondents to complete the questionnaire was 13 min.

The average score of the 30 items for the 407 respondents was >4, and the scores for each item are detailed in Table III.

Reliability and validity

The internal consistency of the 30 items measured by Cronbach's α was 0.964, which was >0.9, proving good

Table III
Competency model for hospital infection prevention and control practitioners: questions and response characteristics (N=407)

Items	Highest score	Lowest score	Mean	SD
a1	5	3	4.92	0.304
a2	5	3	4.84	0.427
a3	5	2	4.84	0.438
a4	5	1	4.88	0.403
a5	5	3	4.87	0.368
a6	5	3	4.90	0.322
a7	5	3	4.86	0.389
a8	5	3	4.91	0.338
a9	5	3	4.89	0.334
a10	5	3	4.91	0.316
a11	5	3	4.91	0.304
a12	5	3	4.82	0.421
b1	5	3	4.87	0.372
b2	5	1	4.56	0.692
b3	5	1	4.57	0.688
b4	5	3	4.71	0.531
b5	5	2	4.66	0.603
b6	5	1	4.72	0.561
b7	5	1	4.71	0.617
c1	5	2	4.79	0.462
c2	5	2	4.81	0.434
c3	5	2	4.78	0.463
c4	5	3	4.84	0.393
c5	5	2	4.79	0.451
c6	5	3	4.85	0.393
d1	5	3	4.84	0.391
d2	5	3	4.81	0.424
d3	5	1	4.79	0.484
d4	5	2	4.80	0.453
d5	5	2	4.86	0.386

SD, standard deviation.

credibility of the scale. The content validity of the questionnaire was verified by the Delphi method. Factor analysis of the scales showed a high KMO value of 0.945, indicating the presence of several common factors among the variables. In addition, the Bartlett's test revealed a Chi-squared value of 10523.239 (df=435; P<0.001), suggesting the presence of common factors between correlation matrices and the scale suitable for factor analysis. The scale had high structural validity, and it can be used for further factor analysis.

Exploratory factor analysis

The five-factor model and the six-factor model showed better indicators than the other models (Table S2, see online supplementary material). However, one factor in the six-factor model contained fewer than three items, so the five-factor model was selected.

In the five-factor model, the factor loading of 'teamwork' (c4) and 'emergency organization' (c6) were both lower than 0.4 in each dimension that they could not be judged as specific factors. Moreover, 'learning skill' (b1) had a factor loading <0.4 in each dimension. In addition, 'psychological counselling ability' (b7) appeared in two factors simultaneously, but the factor loading difference was <0.1. Hence, the two items could not explain specific factors. Due to the low interpretability, the four items were deleted. All other items showed high factor loading of one factor, but low loading of other factors. Also, each item had a clear conceptual meaning.

The project portfolio of the five-factor model was different from the original model. Factor 1 remained 'professional skill', and included items a1, a5, a6, a7, a8, a9, a10, a11 and a12. Factor 2 was a new dimension, and included items a2, a3 and a4. At the beginning, items a2, a3 and a4 belonged to factor 1, but, based on the results of data analysis and the actual situation of major public health emergencies, it was named 'normalization management ability'. Factor 3 was named 'professional development capability', and included items b2, b3, b4 and b5. Factor 4 was named 'organizational collaboration ability', and included items c1, c2, c3 and c5. Factor 5 was 'personal trait', and included items d1, d2, d3, d4, d5 and b6. Item b6 refers to the ability to adapt to different environments; it originally belonged to 'professional development capability', but was later found to be more suitable for 'personal trait'. Table IV lists the five factors and the definitions of the remaining 26 items.

Confirmatory factor analysis

The results of CFA were as follows: TLI=0.911, CFI=0.921, SRMR=0.053 and RMSEA=0.044, indicating a good fit. Furthermore, Cronbach's α for each dimension showed good reliability: F1, 'professional skill' α=0.921; F2, 'normalization management ability' α=0.855; F3, 'organizational collaboration ability' α=0.895; F4, 'professional development capability' α=0.918; and F5, 'personal trait' α=0.918. Table V lists the factor loadings of the 26 items, and Figure 1 illustrates the competency model.

Discussion

This study verified the competency of HIPCPs in the post-pandemic era. The results revealed that the scale had good reliability and validity. Therefore, it is an appropriate scientific tool to comprehensively measure the competency of HIPCPs in the post-pandemic era.

The final scale was a five-dimensional model consisting of 26 items. The five factors were: F1, 'professional skill'; F2, 'normalization management ability'; F3, 'professional development capability'; F4, 'organizational collaboration ability'; and F5, 'personal trait'. The final framework was slightly different from the initial assumptions, but may better highlight the characteristics of the capabilities required by HIPCPs in the post-pandemic era, and conformed to the theoretical framework established via the literature review, key informant interviews and the Delphi expert consultation. For example, factors 3, 4 and 5 were similar to the theoretical framework. Although factor 2 was separated from theoretical factor 1, the items were classified in more detail, emphasizing the importance of the normalized managerial ability of HIPCPs irrespective of emergencies or routine periods ['statistical reporting' (a2), 'quality control' (a3), 'management and control' (a4)].

Nosocomial infections of varying degrees form an essential part of an epidemic. Improving the ability of HIPCPs to manage nosocomial infections is the key to the current epidemic phase [2]. The existing research recognizes the critical role played by

Table IV
Definition of 26 items of the five-dimensional competency model

Factors	Definition
F1	a1 Monitor hospital dynamics, identify and assess risks in time
	a5 Reasonably set up emergency places and isolation locations
	a6 Familiar with hospital infection regulations, hospital emergency treatment standards and norms
	a7 Propose amendments to nosocomial infection regulations based on the actual situation
	a8 Respond quickly to epidemic prevention and control requirements, and formulate targeted hospital infection prevention and control plans
	a9 Supervise and guide the implementation of infection prevention and control measures
	a10 Instruct medical staff in infection prevention skills
	a11 Self-infection prevention awareness and skills
	a12 Provide health education on infectious disease prevention and control knowledge
F2	a2 Conduct periodic epidemiological investigations and statistical analysis, timely and accurate reporting
	a3 Carry out quality supervision on infection prevention and control supplies
	a4 Strict management of key locations, such as ward entrances and exits
F3	b2 Grasp new developments in infection prevention and control in a timely manner and carry out scientific research
	b3 Rational planning of career development
	b4 Skillfully operate the information platform and media platforms
	b5 Information sensitivity and delivery awareness
F4	c1 Meet the basic needs of hospital departments for prevention and control resources
	c2 Timely organization of medical institution personnel to carry out unified training
	c3 Timely and orderly mobilization and allocation of resources
	c5 Strong sense of cooperation
F5	d1 Working in high-pressure environments
	d2 Dedication
	d3 Perseverance
	d4 Make quick judgements and decisions in emergency
	d5 Responsibility
	b6 Adaptability to different working environments

the competency model for HIPCPs in ensuring the quality of hospital infection prevention and control. The eight-dimensional examination content online [8] and the four-domain core competency framework [14] provided the standardized measurement of expertise for HIPCPs, and promoted professionalism among practitioners towards infection prevention and control to decrease the occurrence of nosocomial-infection-related adverse events. However, numerous nosocomial infection events during the COVID-19 pandemic exposed the issues of HIPCPs cultured under the existing standards, and also provided new directions for competency training. Therefore, a new competency framework has been proposed by the authors based on their experience in response to the COVID-19 pandemic. Information technology elements ['advanced technique skill' (b4), 'information awareness' (b5)] have been included in this scale in addition to the key elements highlighted in previous studies and guidelines. Advanced information technology has played a crucial role in the prevention and control of COVID-19 in diverse ways [2]; for example, digital technologies (BigData and cloud computing) have been used extensively to control and prevent outbreaks and telework with remote-vision medical systems and to disseminate information about nosocomial infections in a timely manner [21,22]. Mastering advanced information technology skills is expected to provide technical conditions for the development of higher-quality hospital infection prevention and control, and to reduce nosocomial infections [23].

Moreover, differing from others, the present scale presents emergency response competence items (such as 'resource coordination', 'layout and reconstruction of the emergency site' and 'supervision and guidance'), which were proven to be important in the COVID-19 pandemic [18,24,25]. With the surge in numbers of infected cases, various medical needs have increased dramatically during the pandemic. Therefore, the deployment and supply of healthcare personnel, equipment and drugs are of great significance to the efficiency of treatment and for the control of the pandemic [2]. Moreover, HIPCPs should place patients separately, based on their risk levels, in partitioned temporary emergency sites to reduce the risk of cross-infection [26]. Furthermore, each hospital department must conduct infection prevention and control measures towards reducing the risk of nosocomial infections, especially rational disposal of medical waste, considering that incorrect methods directly increase the risk of infection [27,28]. Thus, HIPCPs need to provide professional training on the knowledge and skills of the pandemic emergency response of healthcare workers and conduct daily supervision [29]. These dimensions and items indicated that the new scale may measure the ability of HIPCPs in the post-pandemic era more comprehensively compared with previously formulated tools.

This study had some limitations. The research results show that HIPCPs tend to respond more positively and affirmatively, known as 'positive skewness'. This shows that they have a strong identity themselves with the proposed competency

Table V
Factor loading estimates for the confirmatory factor analysis model

Factors	Items	Standardized factor load	SE
F1 Professional skill	a1 Monitoring and risk assessment	0.696	0.055
	a5 Layout and reconstruction of emergency site	0.698	0.053
	a6 Rules and regulations	0.773	0.047
	a7 Feedback and suggestions	0.813	0.031
	a8 Contingency planning	0.769	0.039
	a9 Supervision and guidance	0.792	0.036
	a10 Skill instruction	0.800	0.041
	a11 Self-protection	0.717	0.053
	a12 Health education	0.747	0.036
F2 Normalization management ability	a2 Statistical reporting	0.806	0.033
	a3 Quality control	0.892	0.026
	a4 Management and control	0.758	0.044
F3 Professional development capability	b2 Scientific research	0.892	0.015
	b3 Occupational planning	0.861	0.023
	b4 Advanced technique skill	0.857	0.019
	b5 Information awareness	0.845	0.020
F4 Organizational collaboration ability	c1 Meeting basic needs	0.856	0.024
	c2 Organize and conduct training	0.859	0.025
	c3 Resource coordination	0.772	0.035
	c5 Collaboration	0.824	0.025
F5 Personal trait	d1 Stress resistance	0.748	0.038
	d2 Dedication	0.869	0.022
	d3 Persevere	0.887	0.016
	d4 Decisiveness	0.844	0.032
	d5 Responsibility	0.826	0.028
	b6 Adaptability	0.743	0.037

SE, standard error.

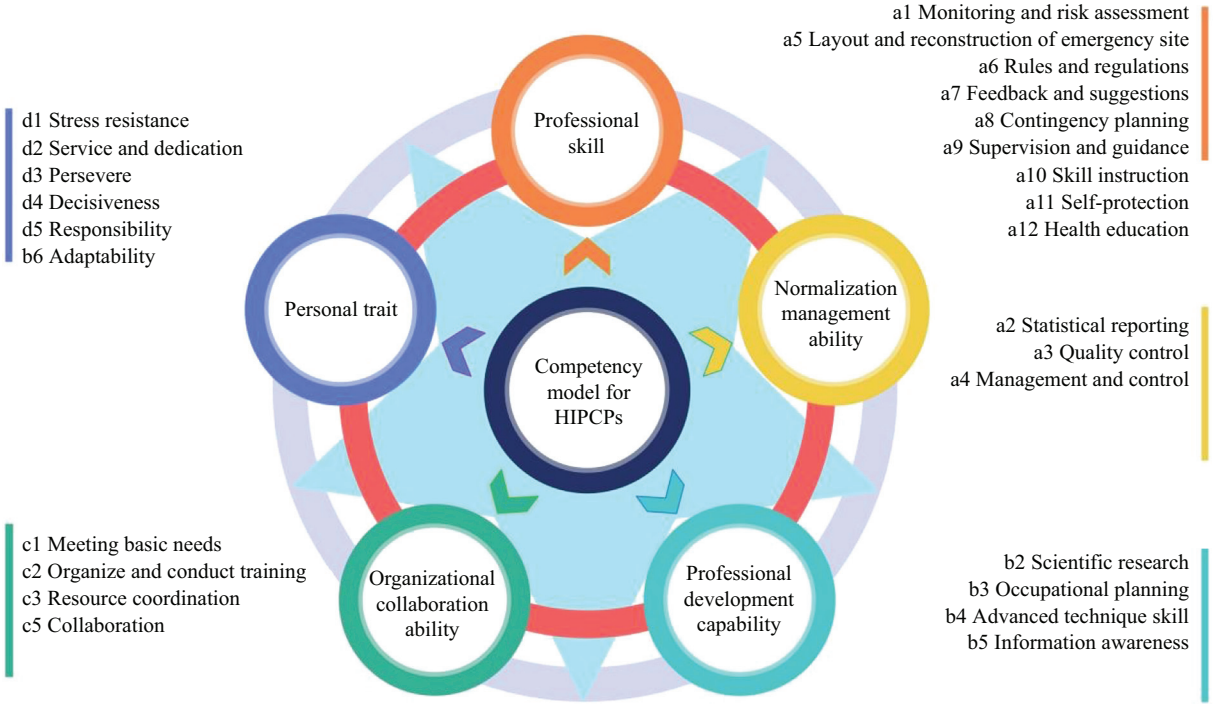

Figure 1. Competency model for hospital infection prevention and control practitioners (HIPCPs).

elements. However, as the investigator responded on the research scale, the answers to the questions were prone to subjective deviations. Therefore, subsequent research is needed for further improvement and objective verification. Some studies have shown that China's HIPCP reserve force is weak, and China needs to provide higher education or further training [18,30]. Thus, further research should be undertaken to study the scope of higher education and professional training of the concerned personnel in order to improve their level of professionalism and capabilities in a focused manner. Personnel must continuously improve their professional capabilities to cope with various nosocomial infection situations and new challenges. Moreover, there is a need for complete understanding of the needs of HIPCPs, the direction of their professional development, the existing problems of nosocomial infection prevention and control, and timely adjustment and improvement of the competency evaluation scale to effectively improve the quality, efficiency and safety of medical services.

In conclusion, the competency model for HIPCPs in the post-pandemic era constructed in this study included five dimensions and 26 items that were developed based on the experiences and lessons learned during the COVID-19 pandemic. The proposed scale can be used to prevent and control occurrences of nosocomial infections in other countries to promote the level of professionalism concerning HIPCP teams, and to develop a solid guide to respond to nosocomial infection control of public health emergencies.

Acknowledgements

The authors wish to thank all interviewers for data collection, and all medical staff involved in fighting against the COVID-19 pandemic for their support and valuable opinions.

Conflict of interest statement
None declared.

Funding source
None.

Author contributions
Ziling Ni and Lu Cui conceived the study, and Ying Wang and Lu Cui interpreted the data. Lu Cui, Ziling Ni, Xiaohe Wang and Xianhong Huang drafted and revised the manuscript. Lu Cui and Anning He undertook the statistical analysis. All authors have approved the final version of the manuscript for publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2021.08.028.

References

[1] World Health Organization. WHO Director-General's opening remarks at the World Health Assembly. Geneva: WHO; 2020. Available at: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-world-health-assembly [last accessed May 2020].

[2] Du Q, Zhang D, Hu W, Li X, Xia Q, Wen T, et al. Nosocomial infection of COVID-19: a new challenge for healthcare professionals. Int J Mol Med 2021;47:31.

[3] Lu D, Wang H, Yu R, Yang H, Zhao Y. Integrated infection control strategy to minimize nosocomial infection of coronavirus disease 2019 among ENT healthcare workers. J Hosp Infect 2020. https://doi.org/10.1016/j.jhin.2020.02.018.

[4] 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.

[5] Lee I, Wang C, Lin M, Kung C, Lan K, Lee C. Effective strategies to prevent coronavirus disease-2019 (COVID-19) outbreak in hospital. J Hosp Infect 2020;105:102—3.

[6] Wulf KKJG. Nosocomial infections. Anasthesiol Intensivmed Notfallmed Schmerzther 2010;30—1.

[7] Harada S, Uno S, Ando T, Iida M, Takano Y, Ishibashi Y, et al. Control of a nosocomial outbreak of COVID-19 in a university hospital. Open Forum Infect Dis 2020;7:ofaa512.

[8] Certification Board of Infection Control and Epidemiology. 2020 candidate handbook. Milwaukee, WI: CBIC; 2020.

[9] Murphy DM, Hanchett M, Olmsted RN, Farber MR, Lee TB, Haas JP, et al. Competency in infection prevention: a conceptual approach to guide current and future practice. Am J Infect Control 2012;40:296—303.

[10] Gase KA, Leone C, Khoury R, Babcock HM. Advancing the competency of infection preventionists. Am J Infect Control 2015;43:370—9.

[11] Hansen S, Zingg W, Ahmad R, Kyratsis Y, Behnke M, Schwab F, et al. Organization of infection control in European hospitals. J Hosp Infect 2015;91:338—45.

[12] Burnett E, Curran E, Loveday HP, Kiernan MA, Tannahill M. The outcome competency framework for practitioners in infection prevention and control: use of the outcome logic model for evaluation. J Infect Prev 2014;15:14—21.

[13] Infection Prevention Society. Infection prevention & control practitioner competency assessment summary. Bathgate: IPS; 2019.

[14] Infection Prevention Society. Competency framework for infection prevention & control practitioners. Bathgate: IPS; 2019.

[15] Chan WF, Bond TG, Adamson B, Chow M. Identifying core competencies of infection control nurse specialists in Hong Kong. Clin Nurse Spec 2016;30:E1—9.

[16] He Y, Li W, Wang Z, Chen H, Tian L, Liu D. Nosocomial infection among patients with COVID-19: a retrospective data analysis of 918 cases from a single center in Wuhan, China. Infect Control Hosp Epidemiol 2020;41:982—3.

[17] Bardi T, Pintado V, Gomez-Rojo M, Escudero-Sanchez R, Azzam Lopez A, Diez-Remesal Y, et al. Nosocomial infections associated to COVID-19 in the intensive care unit: clinical characteristics and outcome. Eur J Clin Microbiol 2021;40:495—502.

[18] Ye Q, Yang J, Cheng Y, Dong W. How to strengthen the training on hospital infection control during the COVID-19 pandemic. Chin J Med Educ 2020;40:490—4.

[19] Ponce-Alonso M, Sáez De La Fuente J, Rincón-Carlavilla A, Moreno-Nunez P, Martínez-García L, Escudero-Sánchez R, et al. Impact of the coronavirus disease 2019 (COVID-19) pandemic on nosocomial *Clostridioides difficile* infection. Infect Control Hosp Epidemiol 2021;42:406—10.

[20] Rickman HM, Rampling T, Shaw K, Martinez-Garcia G, Hail L, Coen P, et al. Nosocomial transmission of coronavirus disease 2019: a retrospective study of 66 hospital-acquired cases in a London teaching hospital. Clin Infect Dis 2021;72:690—3.

[21] Chen P, Sun Q, Chen W, Wang H, Chen X, Zhao C, et al. Countermeasures for prevention and control of infection in patients and medical staff of specialized hospital of COVID-19. Chin J Nosocomiol 2020;30:1490—3.

[22] Yao J, Chen X-J, Xing H. Management of whole process of healthcare-associated infection based on new media. Chin J Infect Control 2018;17: 989—92, 997.

[23] Ge M. Prevention and control of healthcare-associated infection in information age. West Chin Med J 2020;35:280—4.
[24] Guo L-P, Wang Y-L, Zhu R-F, Yao Y, Wang Q-R, Li G, et al. Practical strategies for prevention and control of nosocomial infection in COVID-19 designated hospitals in Wuhan. Chin J Nosocomiol 2020;30:1125—30.
[25] Suo J-J, Yan Z-Q, Liu Y-X, Chai G-J. Current status of hospital-acquired COVID-19 and strategies for prevention and control. Chin J Nosocomiol 2020;30:811—6.
[26] Romano MR, Montericcio A, Montalbano C, Raimondi R, Allegrini D, Ricciardelli G, et al. Facing COVID-19 in ophthalmology department. Curr Eye Res 2020;45:653—8.
[27] Yu H, Sun X, Solvang WD, Zhao X. Reverse logistics network design for effective management of medical waste in epidemic outbreaks: insights from the coronavirus disease 2019 (COVID-19) outbreak in Wuhan (China). Int J Environ Res Publ Health 2020;17:1770.
[28] Awodele O, Adewoye AA, Oparah AC. Assessment of medical waste management in seven hospitals in Lagos, Nigeria. BMC Publ Health 2016;16:269.
[29] Wang H, Wang S, Yu K. COVID-19 infection epidemic: the medical management strategies in Heilongjiang Province, China. Crit Care 2020;24:107.
[30] Li L. New technique and progress of prevention and control of healthcare-associated Infection. West Chin Med J 2018;33:240—3.