Development and Validation of the Competency Evaluation Model for Hospital Infection Prevention and Control Practitioners in the Post-Pandemic Era: A Mixed Methods Study

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Research

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Abstract

Background

This study was undertaken to determine the practitioners' competence in relation to the hospital infection prevention and control measures that is significant for their professional development as well as to ascertain their role in the prevention and control activities against nosocomial infection. During the current COVID-19 pandemic situation, the hospital infection management has become crucial, which has necessitated the urgency of developing a competency model for healthcare practitioners to combat public health emergencies.

Method:

On the basis of literature review, the key informant interviews, the Delphi method and the questionnaire survey, a theoretical framework and an assessment tool consisting of 26 items were developed. 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 competence model. Measurement invariance of the instruments was determined to ensure that the variables used for the analyses were of similar constructs across the study groups.

Results

The effective response rate on the questionnaires was 88.29%, and the Cronbach's α-coefficient of the scale was 0.964. Factor analysis revealed a KMO of 0.945. The Bartlett's test gave an χ^2 of 10523.439 ($df = 435$; $p < 0.001$). After exploratory factor analysis, the 5-factor model was retained, 4 items were deleted, and a 5-dimensional, 26-item scale was obtained. The new structure's confirmatory factor analysis revealed a high goodness of fit (CFI = 0.933; TLI = 0.925; SRMSR = 0.053; and RMSEA = 0.040). The difference between the indexes of the 2 regions was significant at < 0.1, which confirmed measurement invariance across the regions.

Conclusion

The scale was found to be highly reliable, valid, and credible. Therefore, it can serve as an effective tool for assessing the competencies of hospital infection prevention and control practitioners.

Introduction

COVID-19 was declared a major public health emergency by WHO, which has had an unprecedented impact on the world since the end of 2019 and through 2020 [1]. With the COVID-19 pandemic period, nosocomial infection has become a major problem that could not have been ignored. Hospitals are the main battlefield in the fight against COVID-19, and several countries and regions have reported that people got infected with the virus in the hospitals. Reports have revealed that healthcare personnel were infected with SARS-CoV-2 while providing care in South Korea, Italy, and Japan [2–4]. The same situation occurred with emergency medical technicians

while transporting patients [5]. Epidemiological follow-up of patients with pre-infection also revealed that the early cases were of nosocomial infections. An early research report on 138 COVID-19 cases revealed that 41.3% of the cases were considered to be cases of nosocomial infection, of which 12.3% infections were transferred by the medical staff [6].

Nosocomial infections can have serious consequences. First, medical personnel are an important force involved in the prevention and control measures of the COVID-19 pandemic; hence, if they themselves get infected, this situation would pose a significant challenge in delivery medical services [7]. Healthcare workers account for 3% of the world's population and also account for 14% of all cases of infection [8]. Second, nosocomial infection of COVID-19 directly impacts the quality of medical care and also the safety of the patients [9]. Patients with other diseases are likely to face more severe consequences after acquiring COVID-19 infection, with an increased risk of mortality [10]. Furthermore, it has been reported that one COVID-19 case and 129 related cases occurred in a long-term care facility in Washington, USA, which resulted in 23 deaths [11]. Therefore, nosocomial infections need to be controlled, as this is a crucial step for the prevention of COVID-19 transmission, hence demanding that the hospital infection prevention and control (HIPC) practitioners should be highly competent [12].

Several researchers paid attention to the competence of HIPC practitioners, especially after the SARS outbreak in 2003, and constructed models for measuring the professional competence of the practitioners in multiple dimensions [13]. This research area is being pursued in North America since the 1970s and 4-dimensional competence requirements have been established [14]. At the end of the 20th century, the Association of Professionals in Infection Control and Epidemiology (APIC, America) and Community and Hospital Infection Control Association (CHICA, Canada) jointly compiled the practice and professional competence standards for HIPC practitioners in a written document [15,16]. In 2000, the Infection Control Nurses Association (ICNA) in UK proposed competence standards for the Infection Prevention and Control (IPC) personnel and subsequently updated the standards in 2004. The competence standard framework called for a more comprehensive evaluation model for HIPC practitioners [17,18]. The European Centre for Disease Prevention and Control (ECDC) released a list of core competencies for hospital infection management professionals in 2009 [19]. In 2011, Hong Kong and China studied the core competence model for HIPC practitioners based on the regional characteristics [20]. Although these competency models have been beneficial, while investigating COVID-19, we noted that the current research continues to suffer from many shortcomings, for example, these models no longer meet the current challenges and requirements. Previous studies have neglected the difference between the management of nosocomial infections during public health emergencies and during the normalcy period. These frameworks of competencies fail to meet the requirements of HIPC practitioners, brought forth by the new COVID-19 crisis. Moreover, new technologies are widely being used in the medical field presently, which have played a crucial role in the prevention and control of COVID-19 in various ways, albeit these models have failed to keep up with the present day needs and requirements [9,21].

Therefore, there is an urgent need to propose a HIPC practitioner capacity model that meets the current demands of various countries and regions. The Chinese experience in fighting COVID-19 and the adoption of effective nosocomial infection prevention and control measures can be used as a reference for most countries around the world. Wuhan was the epicenter of the Chinese COVID-19 fight. This study was conducted in the

ZhongNan Hospital of Wuhan University, Leishenshan hospital, and other major pandemic-fighting hospitals. The participants were HIPC practitioners who were involved in the fight against the pandemic in China. Their service capabilities were investigated with the help of a survey, and a competency model for post-pandemic HIPC practitioners was proposed to guide the international fight against COVID-19.

Methods

Research Design

A mixed-method approach was adopted to investigate the service competency of the HIPC practitioners between February 2020 and November 2020. First, on the basis of the Competency Onion Model, a list of competence items was prepared after the completion of the literature review. Second, interviews of HIPC practitioners, as key informants were conducted, to enhance the prevention and control measures for COVID-19 pandemic and to modify the earlier proposed list of competencies as well as to formulate an initial scale. Third, the dimensions and items were optimized using the Delphi method in order to produce the final version of the measurement scale as well as to carry out the survey. Finally, factorial analysis was performed and measurement invariance analysis of the data was conducted, the scale was validated, and a scientific and practical competency model for HIPC practitioners was constructed.

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

Hospital Infection Prevention and Control Practitioner Competence Measurement Scale

The HIPC practitioner competence measurement scale was developed in 3 phases. The first step was to conduct a comprehensive literature review of previous studies based on the competency onion model, followed by the categorization of the evaluation indicators mentioned in 211 pieces of literature related to HIPC practitioners, both in English and Chinese. A total of 328 indexes (including duplicates) were extracted in order to draw a list of items related to competence. Conduction of interviews of the key informants interviews was the second step. Semi-structured interviews with HIPC practitioners, who were involved in the COVID-19 pandemic fight, were then conducted. For this purpose, telephonic interviews of 25-40-min duration of each interviewee were conducted. The interview focused on the implementation, key links, and influencing factors of COVID-19 HIPC, which included 5 parts: (1) the role and orientation of HIPC in public hospitals in the process of fighting against COVID-19; (2) work responsibilities, content, process, and critical points to be taken care of by the department of infection control during normal and in pandemic situations; (3) HIPC goals during the COVID-19 pandemic and strategies and approaches for implementation; (4) factors that promoted and hindered the HIPC of public hospitals during the COVID-19 pandemic; and (5) suggestions for the improvement of the implementation of HIPC during the COVID-19 pandemic. On the basis of the grounded theory, the interview data was subjected to a 3-level strict coding procedure. Based on the qualitative information gathered, the competence entries database was supplemented and an initial competence assessment scale was constructed. In the last step, an expert was appointed and 3 rounds of discussion were conducted by a group of experts, on the HIPC practitioners' competency framework, using the Delphi method. In the first round, the competence dimensions were outlined and, in the latter 2 rounds, the subsequent items were developed.

After considering the coefficient indicators and based on the suggestions of the experts, the research team finally selected 30 items related to the 4 dimensions to construct the final scale. The four dimensions included professional skill, professional development capability, organizational collaboration ability, and personal trait.

Data Analysis

For the purpose of validation of the competence scale for HIPC, the collected data was analyzed.

Factor Analysis

The responses of 30 items of the scale were used to reduce the data into several latent factors through factor analysis. The Mplus version 8.0 was used to perform the factor analysis in 2 steps: the exploratory factor analysis and confirmatory factor analysis.

First of all, exploratory factor analysis (EFA) was used to determine the potential factor structure of 30 items and to select the best factors, without making any prior assumptions about the relationship between them. The scale was originally constructed as a 4-factor model, but, later, a two-six factor EFA analysis was performed to improve the exploratory nature. The factor loading of 0.40 was selected as the cut-off value to determine the items that were strongly related to the given factor. Second, confirmatory factor analysis (CFA) was used to verify the goodness of fit of the potential factors and for the standardization of the model. The Chi-Square Test of Model Fit (X^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% C.I) were selected as the evaluation index for evaluating the adequacy of the scale (TLI > 0.90; CFI > 0.90; and RMSEA < 0.05), indicating a good fit.

Measurement Invariance

The possibility of measurement invariance between 2 regions: Eastern China and Midwest China (divided by the administrative regions) was evaluated to ascertain whether the respondents from the 2 regions provided a similar explanation of the items. The existence of measurement invariance meant that HIPC practitioners working in different geographic areas, interpret the scale in the same way. If the CFI difference between the eastern model (G1) and the mid-west model (G2) was ≤ 0.1, the invariant assumption was not rejected, which meant that most factor loading parameters between the 2 groups were similar. If RMSEA ≤ 0.08, there was no direct evidence that the test model was a poor fit.

Results

Key Informant Interviews

A total of 12 interview records were transcribed to formulate the 5 main concept categories: (1) the background of execution of prevention and control execution; (2) action strategy; (3) the plan for implementation, (4) support conditions, (5) obstacles in execution, and 19 sub-categories (Table 1 at the end of the document). We found that the front-line prevention and control workers of the COVID-19 pandemic not only have frequent references to "orderly multi-department coordination", "screening ability of protective and disinfectant products", "building layout and its timely reconstruction" and "effective ability training in emergencies" but also frequently mentioned cases related to the implementation of informatization of hospital

infection management. Therefore, we added 6 items: "Resource coordination", "Quality control", "Layout and reconstruction of emergency site", "Supervision and guidance", "Information technology", and "Internet plus".

Table 1
Hospital infection prevention and control concept category and scope

Number	Concept categories	Sub-categories
1	The background of execution of prevention and control execution	1.Pandemic status 2.Political directives 3.Infection prevention and control needs
2	Action strategy	1.Three-tier action strategy for hospital infection management 2.Organizing departmental cooperation 3.Infection management work execution system building
3	The plan for implementation	1.Infection prevention and control plan 2.Standard precautions and supplementary precautions 3.Isolation measures 4.Strict disinfection 5.Full process personnel training 6.Isolation site layout
4	Support conditions	1.Specialized workforce 2.Human resources and protective products supplies 3.Informatization construction 4.Technology guide
5	Obstacles in execution	1.Varying levels of clinical practice 2.lack of professionals 3.Lack of uniform emergency training

Delphi Method

The experts suggested that the second-level and the third-level items should be merged to avoid excessive items and duplication of the items in the questionnaires.

The experts felt that the item "Surveillance and report" could not reflect the specific ability requirements and suggested that it can be divided into "Monitoring and risk assessment" and "Statistical reporting". Furthermore, the experts found that the expression of "Perfecting supervision system" was incorrect because HIPC

practitioners do not have the power to formulate the regulations and recommend amendments for "Feedback and suggestions".

In addition, the experts also mentioned that the definition of "Occupational health" is too vague and broad, and they proposed to it into "Protection guidance" and "Self-protection" according to different target groups. The experts also pointed out that "Adaptability" and "Psychological counseling" were the developmental capacity manifested in this pandemic,thus they should be generalized in "Professional development capability". Table 2 (at the end of the document) shows the final competency scale, which contains the elements and definitions of 30 items in the 4-dimension HIPC practitioners.

Table 2
Key elements for the evaluation of HIPC practitioners in the post-pandemic era

Dimensions		Key elements	Definition
Professional skill	a1	Monitoring and risk assessment	Monitor hospital dynamics, identify and assess risks in time
	a2	Statistical reporting	Conduct periodic epidemiological investigations and statistical analysis and interpretation of data, and report timely and accurately
	a3	Quality control	Carry out quality supervision on prevention and control medical related supplies
	a4	Management and control	Strict management and control of key locations such as hospital environmental sanitation and ward entrances and exits
	a5	Layout and reconstruction of emergency site	Reasonably set up emergency places and isolation locations for hospital epidemics
	a6	Rules and regulations	Familiar with hospital infection rules and regulations, hospital emergency treatment standards and norms
	a7	Feedback and suggestions	Feedback and timely suggestion of the nosocomial infection-related regulations for hospitals according to the actual situation
	a8	Contingency Planning	Respond quickly to epidemic prevention and control requirements, and quickly formulate targeted hospital infection prevention and control plans
	a9	Supervision and guidance	Supervise and guide the implementation of epidemic prevention and control measures
	a10	Protection guidance	Instruct medical staff on occupational health and reduce the risk of cross-infection in the hospital
	a11	Self-protection	Have self-protection awareness and protection skills
	a12	Health education	Provide health education and consultation on infectious disease prevention and control related knowledge
Professional development capability	b1	Learning skill	Actively learn relevant professional knowledge to improve self-professional skills
	b2	Scientific research	Timely grasp the new developments in infection prevention and control at home and abroad and carry out further scientific research and innovation
	b3	Occupational planning	Reasonably plan career development
	b4	Information technology	Skillfully operate the information platform
	b5	Internet plus	Internet plus consciousness and new media platform utilization ability

Dimensions		Key elements	Definition
	b6	Adaptability	Adaptability to different working environments
	b7	Psychological counseling ability	Provide psychological counseling to patients or colleagues
Organizational collaboration ability	c1	Meeting basic needs	Have a modern and comprehensive management awareness to meet the basic needs of prevention and control of various departments
	c2	Organization of training	Organize medical institution personnel to conduct unified training throughout the process in time
	c3	Resource coordination	Timely and orderly mobilize and allocate human resources and material resources
	c4	Teamwork	Have team spirit, can communicate, understand and support each other with team members
	c5	Collaboration	Friendly communication and cooperation with experts and colleagues
	c6	Emergency organization	In emergencies, the ability to organize teams with a clear division of labor urgently
Personal trait	d1	Stress resistance	Can working under high pressure and extreme stress
	d2	Service and dedication	Have a sense of service and dedication
	d3	Persevere	Have perseverance and passion
	d4	Decisiveness	Quickly make judgments and make correct decisions in emergency
	d5	Responsibility	Have a sense of responsibility

Respondents and Questions

The survey was conducted on 461 HIPC practitioners from 15 provinces in China, who were involved in the prevention and control of the COVID-19 pandemic. We recorded 54 invalid questionnaires with missing or incomplete information and they were excluded, the practical response rate was 88.29%. Among the respondents, 78.13% were women. The 31–40-years age group included 128 participants, the 41–50-years age group contained 151, and the two age groups accounted for 68.55% of the total number of people. In addition, 80.34% of the respondents had clinical, public health, nursing professional education background; and those having bachelor degree or above accounted for 65.02% of the respondents. A total of 249 people with middle titles or above accounted for 58.97%. In China, the professional designations of HIPC practitioners included junior technologist), middle (technologist-in-change), deputy senior (senior associate technologist), and senior (full senior technologist). Moreover, 79.31% of the total respondents had participated in hospital infection management work for > 5 years, of which 195 were from tertiary hospitals, 140 were from secondary hospitals, and 72 were from primary hospitals.

The average time take by the respondents to complete the questionnaire was 13 min. The average score of the 30 items from the 407 respondents was > 4. The scores obtained on the scale have been illustrated in Table 3 (at the end of the document).

Table 3
HIPC practitioners' competency model questions and response characteristics (n = 407).

Items	Minhighest 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

Items	Minhighest score	Lowest score	Mean	SD
d4	5	2	4.80	0.453
d5	5	2	4.86	0.386

Reliability and Validity

The internal consistency of the 35 items measured by Cronbach α was 0.964, which was greater than 0.9, proving credibility of the scale. The content validity of the questionnaire was verified by the Delphi expert consultation method. Factor analysis of the scale showed that the KMO value was high at 0.945 ($p = 0.000$; $p < 0.05$), and the Barlett sphere test result revealed a chi-square value of 10523.239 ($df = 435$; $p = 0.000$; p0.01), which indicated that there are common factors between correlation matrices and the scale was suitable for factor analysis. The scale had high structural validity, which is why it can be used for further factor analysis. Based on the initial HIPC practitioners competence model, the correlation between each of the 30 items and their academic fields was stronger than the correlation between each project and the other 3 fields.

Factor Analysis

Exploratory Factor Analysis

The oblique rotation method was applied to create a simple factor structure and the fitting index of the 5-factor model was relatively better. (Table 4) Through EFA, it was found that the two questions, "Have team spirit, can communicate, and understand and support each other with team members" (c4) and "In emergencies, the ability to organize teams with a clear division of labor urgently" (c6), their factor loading were so low (both < 0.4) that they cannot be judged as specific factors. Moreover, the item "Actively learn relevant professional knowledge to improve self-professional skills" (b1) appeared in both factor 1 and factor 4. The factor load was between 0.35 and 0.4. Besides, "Psychological counseling ability" (b7) appeared in two factors simultaneously, and the factor loading difference was < 0.1. Both of the two items could not explain their specific attributional factors. Due to their low interpretability, it was decided that the 4 questions from the model should be deleted. The EFA factor analysis yielded a 5-factor model with theoretical significance (Fig. 1). Thus, all items showed high factor loading of one factor, but low loading of other factors. Also, each item had a clear conceptual meaning.

Table 4
Fitting information indicators for the EFA model

Factor	χ^2	df	TLI	CFI	AIC	BIC	SRMR	RMSEA(90%CI)
2-factor	971.818*	376	0.793	0.821	5939.359	6038.802	0.054	0.062(0.058 0.067)
3-factor	711.662*	348	0.864	0.891	5281.146	5403.988	0.041	0.051(0.045 0.056)
4-factor	637.936*	321	0.871	0.905	4987.437	5132.842	0.033	0.049(0.044 0.055)
5-factor	540.841*	295	0.891	0.926	4739.965	4907.097	0.027	0.045(0.039 0.051)
6-factor	511.946*	270	0.883	0.927	4597.718	4785.742	0.024	0.047(0.041 0.053)

Confirmatory Factor Analysis

Endogenous latent variables competency is affected by exogenous latent variables F1, F2, F3, F4, and F5; and these exogenous latent variables are measured by observed endogenous variables (such as items a1-d5). According to the results, X^2 = 478.408*; df = 289; (p = 0.0000), TLI = 0.925; CFI = 0.933, SRMR = 0.053, RMSEA (90% CI) = 0.040 (0.034 0.046), indicated that the data was reliable. All the relevant indicators showed that the model was a good fit.

The project portfolio of the 5-factor model was different from the original one. Factor 1 was marked as "Professional skills", and the items were a1, a5, a6, a7, a8, a9, a10, a11, and a12. Factor 2 is a new dimension, had a2, a3, and a4 items. In the beginning, a2, a3, and a4 items belonged to factor 1, but, based on the results of data analysis and the actual situation of major public health emergencies, it was named termed "Normalization management ability"; Factor 3 was named "Professional development capability", which included the items b2, b3, b4, and b5. Factor 4 was termed "Organizational collaboration ability" and had the items c1, c2, c3, and c5. Factor 5 was termed "Personal trait", which included items d1, d2, d3, d4, d5, and b6. b6 refers to the ability to adapt to different environments, it initially was kept under "Professional development capability", but was later found to be more suitable to be put under the "Personal trait”. Table 5 (at the end of the document) lists the labels of these 5 factors and the factor loadings of the remaining 26 items.

Table 5
Factor loading estimates for the CFA model

Factors	Items	Definition	Standardized factor load	S.E.
F1 Professional skill	a1Monitoring and risk assessment	Monitor hospital dynamics, identify and assess risks in time	0.696	0.055
	a5Layout and reconstruction of emergency site	Reasonably set up emergency places and isolation locations for hospital epidemics	0.698	0.053
	a6Rules and regulations	Familiar with hospital infection rules and regulations, hospital emergency treatment standards and norms	0.773	0.047
	a7Feedback and suggestions	Feedback and timely suggestion of the nosocomial infection-related regulations for hospitals according to the actual situation	0.813	0.031
	a8Contingency Planning	Respond quickly to epidemic prevention and control requirements, and quickly formulate targeted hospital infection prevention and control plans	0.769	0.039
	a9Supervision and guidance	Supervise and guide the implementation of epidemic prevention and control measures	0.792	0.036
	a10Protection guidance	Instruct medical staff on occupational health and reduce the risk of cross-infection in the hospital	0.800	0.041
	a11Self-protection	Have self-protection awareness and protection skills	0.717	0.053
	a12Health education	Provide health education and consultation on infectious disease prevention and control related knowledge	0.747	0.036
F2 Normalization management ability	a2Statistical reporting	Conduct periodic epidemiological investigations and statistical analysis and interpretation of data, and report timely and accurately	0.806	0.033
	a3Quality control	Carry out quality supervision on prevention and control medical related supplies	0.892	0.026
	a4Management and control	Strict management and control of key locations such as hospital environmental sanitation and ward entrances and exits	0.758	0.044

Factors	Items	Definition	Standardized factor load	S.E.
F3 Professional development capability	b2Scientific research	Timely grasp the new developments in infection prevention and control at home and abroad and carry out further scientific research and innovation	0.892	0.015
	b3 Occupational planning	Reasonably plan career development	0.861	0.023
	b4Information technology	Skillfully operate the information platform	0.857	0.019
	b5Internet plus	Internet plus consciousness and new media platform utilization ability	0.845	0.020
F4 Organizational collaboration ability	c1Meeting basic needs	Meet the basic needs of hospital departments for prevention and control	0.856	0.024
	c2Training Capability	Organize medical institution personnel to conduct unified training throughout the process in time	0.859	0.025
	c3Resource coordination	Timely and orderly mobilize and allocate human resources and material resources	0.772	0.035
	c5Collaboration	Friendly communication and cooperation with experts and colleagues	0.824	0.025
F5 Personal trait	d1Stress resistance	Can working under high pressure and extreme stress	0.748	0.038
	d2Service and dedication	Have a sense of service and dedication	0.869	0.022
	d3Persevere	Have perseverance and passion	0.887	0.016
	d4Decisiveness	Quickly make judgments and make correct decisions in emergency	0.844	0.032
	d5Responsibility	Have a sense of responsibility	0.826	0.028
	b6Adaptability	Adaptability to different working environments	0.743	0.037

Measurement Invariance

In the two geographic groups (Eastern and Midwest), we observed no statistical difference in interpreting the competence scale of HIPC practitioners. RMSEA = 0.061, which was less than the standard (0.08); $\chi 2$ = 1015.333; df = 578 (p = 0.0000, which was < 0.05), which revealed that it was a good fitness of test model. It was found that CFI_{G1} = 0.881, CFI_{G2} = 0.869, and the difference between the two indexes was significantly <

0.1, which confirmed that there was no evidence to reject the hypothesis pertaining to the measurement invariance and which confirmed the measurement invariance across regions.

Discussion

This study verified the competence scale of HIPC practitioners in the post-pandemic era. The results reveled that, the scale has good reliability and validity. Therefore, it is an appropriate scientific tool, and a comprehensive competence measurement model of HIPC practitioners. It is a five-dimensional model consisting of 26 items. The dimensions of the scale were as follows: Professional skill; Normalization management ability; Professional development capability; Organizational collaboration ability; and Personal trait.

The new five-dimensional model is somewhat different from our initial assumptions but can better highlight the characteristics of the capabilities required by HIPC practitioners in the post-pandemic era, and it conforms to the theoretical framework established via literature review and the Delphi expert consultation. For example, the indicators of normalization management ability a2, a3 and a4 were separated from a1 and a12 in the original professional basic skill and were classified in more detail. The measurement invariance of the scale was also tested. The indicators proved that the factor structure does not change with geographical regions, which means the model is characterized by generalizability. As a scientific tool, this model can be used, as a standard for emergency training and performance examination of HIPC practitioners and also for comprehensive evaluation of their ability.

Public health emergencies do not occur only once, and we currently do not have the technology and ability to predict and control the pandemic effectively [22]. Therefore, we must pay attention to enhancing our capabilities around nosocomial infection prevention and control. WHO has issued some guidelines regarding this. Various countries and regions have conducted research on the competence levels of health professionals in this field [14]. There are two professional infection prevention and control academic institutions in North America, APIC and CHICA, that have jointly formulated professional standards, practice standards and personal traits for HIPC practitioners [23]. The HIPC practitioners competence model proposed by the British Infection Prevention Society (IPS) contains four core dimensions and seventeen sub-dimensions [18]. The European Centre for Disease Prevention and Control (ECDC) has proposed a list of four-dimension capabilities [19]. A ten-dimensional framework has been proposed by Hong Kong, China [20,24]. These studies have set a good example for the HIPC practitioners within a certain period of time. However, the databases need to be continuously updated. Our 26 items model for HIPC practitioners covers the basic professional skills, development capabilities, interpersonal skills, personal characteristics, and other core capabilities mentioned in the above models. Besides, it is the first time that technical competence as a dimension has been included. Studies have shown that HIPC practitioners leverage information technology to establish infection prevention and control databases to transmit information between internal departments, thus improving the level of risk identification, and for providing an excellent foundation for hospital infection management growth [25,26]. Besides, on the basis of the Chinese experience in the COVID-19 pandemic, medical supplies quality control competence, infection prevention and control measures supervision competence, and emergency site planning ability were included in our model. Control of quality of protective equipment, design and installation of appropriate

isolation places are important for sudden outbreaks [27–30]. In a significant public health emergency, HIPC practitioners provide health education and consultation on the prevention and control of infectious diseases, which helps patients and strengthens their self-protection skills. It is more conducive to the prevention and control of nosocomial infection [31,32]. Thus we propose that this competence item should be included in the professional skills dimension. In addition, the pandemic spreads rapidly and is highly contagious, and the hospital atmosphere becomes tense and anxious. Emergencies are likely to occur frequently. So, as frontline workers, HIPC practitioners need to possess strong ability to deal with such pressure [33], should have work environment adaptability [34], and emergency decision-making capabilities [35] for improving the work quality. Therefore, we added stress resistance, adaptability, and decision-making capabilities to the personal traits. In summary, our research has evaluated the competence of HIPC practitioners more comprehensively than previous studies.

To sum up, our scale provides a more comprehensive assessment of the competence of HIPC practitioners than the previously formulated tools. In the post-pandemic era, our competency research model can provide other countries with experiential lessons and important recommendations for building up teams of HIPC practitioners.

Limitations of the Study

Our research results show that HIPC practitioners tend to respond more positively and affirmatively, which is also known as positive skewness. This shows that they have a strongly identity themselves with the proposed competency elements. However, since 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. This research found that China's HIPC practitioners reserve force is weak, as China currently does not provide for higher education or further training. Thus, our next research plan is to study the higher education and professional training of these personnel to improve their professionalism and capabilities in a focused manner. These personnel must continuously improve their professional capabilities in order to cope up with various nosocomial infection situations and new challenges. Moreover, we need to have a full understanding of the needs of HIPC practitioners, 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.

Conclusions

HIPC practitioners have become more and more important in medical care. The post-pandemic era hospital infection prevention and control practitioners' competency scale verified in this study has 5 dimensions and 26 items that have been developed on the basis of the experiences and lessons learned during the COVID-19 pandemic. It is also the first scale developed in China to assess the competencies of infection prevention and control personnel in the post-pandemic era and has proved to be reliable, effective and credible. This scale can also be used for the prevention and control of nosocomial infections in other countries. It also provides a strong guide for nosocomial infection control of public health emergencies or even the resurgence of COVID-19 in future.

Declarations

Ethics approval and consent to participate: The study was authorized by the Ethics Review Committee of Tongji Medical College, Huazhong University of Science and Technology (IORG No: IORG0003571), according to the principles of the Declaration of Helsinki.

Consent for publication: Not applicable; the manuscript does not contain any individual's data in any form of individual details, images, or videos.

Availability of data and materials: Data supporting the results reported in the article are available from the corresponding author upon reasonable request.

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Authors' contributions: Ziling Ni and Lu Cui conceived the study idea, 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.

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References

1. WHO Director-General's opening remarks at the World Health Assembly: WHO. Available from: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-world-health-assembly. Accessed May 18, 2020.
2. Huh S. How to train health personnel to protect themselves from SARS-CoV-2 (novel coronavirus) infection when caring for a patient or suspected case. J Educ Eval Health Prof 2020;17:10.
3. Colaneri M, Novelli V, Cutti S, et al. The experience of the health care workers of a severely hit SARS-CoV-2 referral Hospital in Italy: incidence, clinical course and modifiable risk factors for COVID-19 infection. J Public Health (Oxf) 2020;Nov 3:fdaa195.
4. Yokoo K, Sugaya F, Matsuzaka S, et al. The first case of COVID-19 occurring as community-acquired pneumonia in Hokkaido, Japan and our preventive measures against nosocomial infection. Respir Med Case Rep 2020;30:101078.
5. Occurrence of positive novel coronavirus cases among health personnel Seoul: JTBC. Available from: http://isplus.live.joins.com/news/article/article.asp?total_id=23721204&ctg=1200&tm=i_lf_3011&tag=.%20total_id=23721204&ctg=1200&tm=i_lf_3011&tag=. Accessed March 3, 2020.
6. Wang D, Hu B, Hu C, et al. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. JAMA 2020;323(11):1061-1069.

7. Lee IK, Wang CC, Lin MC, et al. Effective strategies to prevent coronavirus disease-2019 (COVID-19) outbreak in hospital. J Hosp Infect 2020;105(1):102-103.
8. WHO Director-General's opening remarks at the media briefing on COVID-19 - 14 December 2020. Available from: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---14-december-2020. Accessed December 14, 2020.
9. Du, Q., Zhang, D., Hu, W., et al. Nosocomial infection of COVID-19: A new challenge for healthcare professionals (Review). Int J Mol Med 2021;47(4):1.
10. Deshmukh V, Tripathi SC, Pandey A, et al. COVID-19: a conundrum to decipher. Eur Rev Med Pharmacol Sci 2020;24(10):5830-5841.
11. McMichael TM, Clark S, Pogosjans S, et al. COVID-19 in a Long-Term Care Facility - King County, Washington, February 27-March 9, 2020. MMWR Morb Mortal Wkly Rep 2020;69(12):339-342.
12. Suo JJ, Yan ZQ, Liu YX, et al. Current status of hospital-acquired COVID-19 and strategies for prevention and control. Chinese Journal of Nosocomiology 2020;30(06):811-816.
13. Patricia, Tai-Yin, Ching. Core competencies and professional development of infection prevention and control practitioners (IPCPs) - learning from the international experience. West China Medical Journal 2018;33(03):244-248.
14. Goldrick BA. The Certification Board of Infection Control and Epidemiology white paper: the value of certification for infection control professionals. Am J Infect Control 2007;35(3):150-156.
15. Friedman C, Curchoe R, Foster M, et al. APIC/CHICA-Canada infection prevention, control, and epidemiology: professional and practice standards. Am J Infect Control 2008;36(6):385-389.
16. Feltovich F, Fabrey LJ. The current practice of infection prevention as demonstrated by the practice analysis survey of the Certification Board of Infection Control and Epidemiology, Inc. Am J Infect Control 2010;38(10):784-788.
17. Bennallick M, Tannahill M, Pellowe C, et al. How to make the most of the IPS Outcome Competences for Practitioners in Infection Prevention and Control. Journal of Infection Prevention 2013;14(3):104-107.
18. Burnett E, Curran E, Loveday H, et al. The outcome competency framework for practitioners in infection prevention and control: use of the outcome logic model for evaluation. Journal of Infection Prevention 2014;15(1):14-21.
19. European Centre for Disease Prevention and Control. Core competencies for infection control and hospital hygiene professionals in the European Union. Available from: http://ecdc.europa.eu/en/publications/publications /infection-control-core-comptencies. Accessed 2013.
20. Chan WF, Bond TG, Adamson B, et al. Identifying core competencies of infection control nurse specialists in Hong Kong. Clinical Nurse Specialist CNS 2016;30(1):E1-E9.
21. Li LY. Taking the road of disciplinary developement of hearthcare-associated information management with Chinese characteristics. Chinese Journal of Nosocomiology 2017;27(14):3126-3130+3138.
22. Zhang SZ, Wang Y. Status of the indicator system of communicable diseases prevention and control of medical institutions. Modern Preventive Medicine 2017;44(08):1460-63.
23. Murphy DM, Hanchett M, Olmsted RN, et al. Competency in infection prevention: a conceptual approach to guide current and future practice. Am J Infect Control 2012;40(4):296-303.

24. Chan WF, Adamson B, Chung JW, et al. Validity and reliability of the proposed core competency for infection control nurses of hospitals in Hong Kong. Am J Infect Control 2011;39(3):e11-e13.
25. Chen P, Sun QD, Chen W, et al. Courtesures for prevention and control of information in patties and medical staf of of specialized hospital of COVID-19. Chinese Journal of Nosocomiology 2020;30(10):1490-1493.
26. McCullough PA, Eidt J, Rangaswami J, et al. Urgent need for individual mobile phone and institutional reporting of at home, hospitalized, and intensive care unit cases of SARS-CoV-2 (COVID-19) infection. Rev Cardiovasc Med 2020;21:1-7.
27. Centers for Disease Control and Prevention (CDC). Interim Infection Prevention and Control Recommendations for Healthcare Personnel During the Coronavirus Disease 2019 (COVID-19)Pandemic. Available from: https://www.cdc.gov/coronavirus/2019-ncov/infec-tion-control/control-recommendations.html. Accessed December 14, 2020.
28. Zhao H, Xie SQ, Yang HZ, et al. Info prevention and control-relevant demand of haleth care workers in medical teaam during ing ing ing ang ainst COVID-19. Chinese Journal of Infection Control 2020;19(05):398-403.
29. Xu QH, Liao SY, Jiang ZL, et al. Study of efect of control team on nosocomial infections in medical inpatients. Chinese Journal of Nosocomiology 2015;25(04):948-949+955.
30. Zhong Nanshan: The Covid-19 appears "environmental transmission"!how to respond? Available from: https://www.thepaper.cn/newsDetail_forward_10479939. Accessed December 21, 2020.
31. China NHCotPsRo. Guidance for Corona Virus Disease 2019 Prevention, Control, Diagnosis and Management. In: China NHCotPsRo, ed.: National Health Commission of the People's Republic of China, 2020.
32. Fu Q. Reflection on disciplinary development of healthcare-associated infections management in China. Chinese Journal of Nosocomiology 2017;27(14):3121-25.
33. Wu J, Zeng FH, Liu HN. Sources of pressure of full-time staff in healthcare-associated infection management in a city of Henan Province. Chinese Journal of Infection Control 2019;18(09):877-81.
34. Zhang QH, Huang SH, Fang HM, et al. Practice and thinking of standardized training of medical protection against COVID-19. Journal of Medical Postgraduates 2020;33(10):1084-1086.
35. Ni Z, Wang X, Zhou S, et al. Development of competency model for family physicians against the background of 'internet plus healthcare' in China: a mixed methods study. Hum Resour Health 2020;18(1):64.

Figures

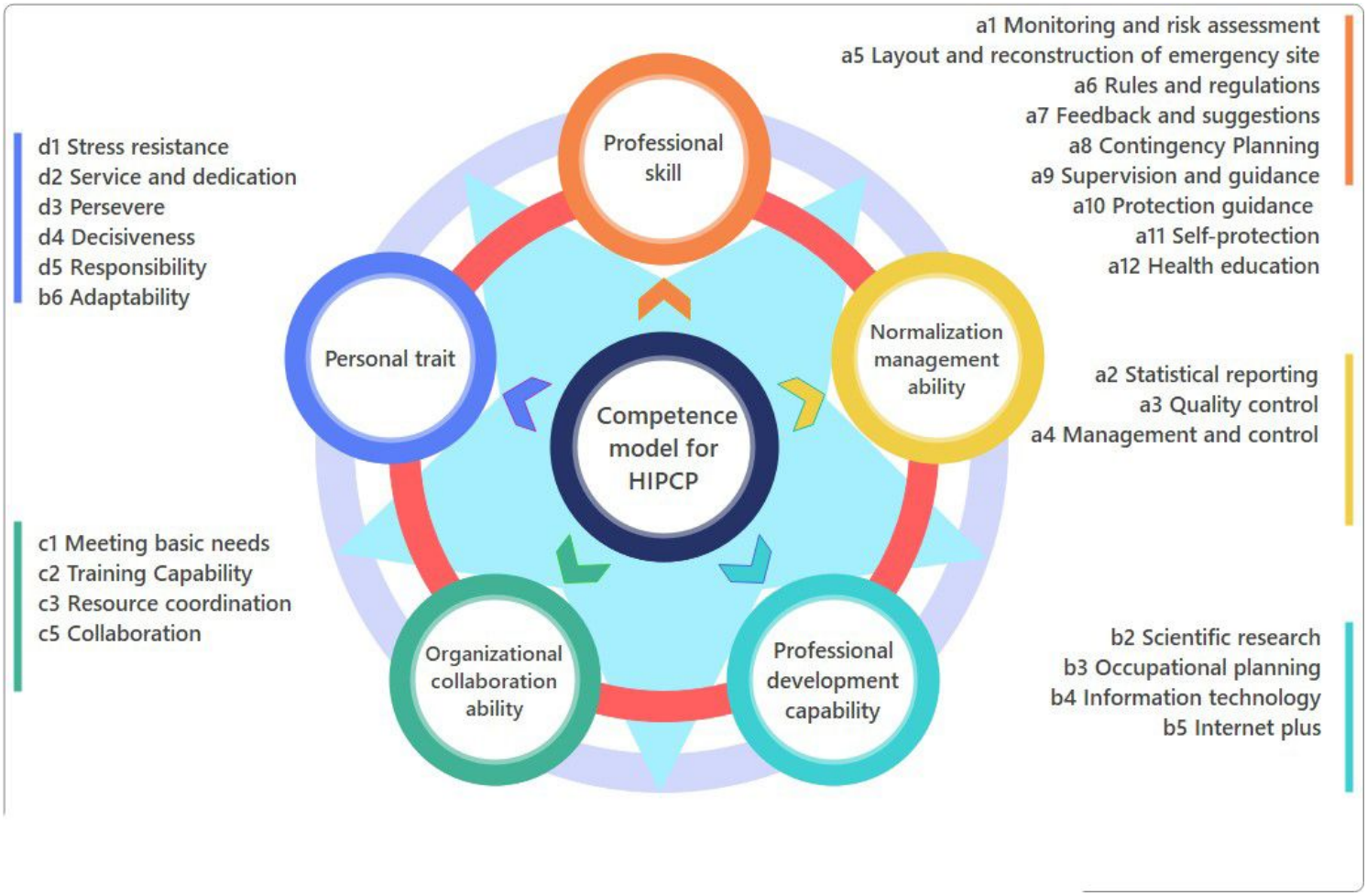

Figure 1

A diagram of competence model for hospital infection prevention and control practitioner. The code represents the meaning of the items specified in Table 5.