

# Kaiser model-based hazard vulnerability analysis in event risk assessment and emergency management of operating room in a hospital in China

*Análisis de vulnerabilidad ante peligros basado en el modelo de Kaiser en la evaluación de riesgos de sucesos y la gestión de emergencias en el quirófano de un hospital de China*

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## Abstract

**Objective:** This study aimed to identify the high-risk events in the operating room so as to provide a decision-making basis for emergency management. **Method:** The Kaiser model-based Hazard vulnerability analysis (HVA) was used to determine the risk matrix. The Delphi method was used to create the risk assessment form. The potential risk events were quantitatively evaluated. The relative risk percentages of the risk events were calculated to identify the top high-risk events. **Results:** A risk matrix containing 4 components (natural disasters; technological hazards; human hazards; and hazardous materials) was determined, and a risk assessment form was created using the Delphi method. The top three high-risk events are as follows: internal radiation exposure (41%), infectious disease outbreaks (38%), and internal fires (33%). The emergency management measures for high-risk events were developed. **Conclusions:** The Kaiser model-based HVA in event risk assessment of operating room can effectively identify potential high-risk events, determine emergency priorities, and optimize resource allocation, thereby ensuring the quality and safety of surgical treatment.

**Keywords:** Operating rooms. Risk assessment. Hospital administration. Safety management. Disasters.

## Resumen

**Objetivo:** Este estudio busca identificar eventos de alto riesgo en quirófano con el fin de proporcionar una base para la toma de decisiones en la gestión de emergencias. **Método:** Para determinar la matriz de riesgos se utilizó el análisis de vulnerabilidad de peligros (HVA) basado en el modelo de Kaiser. Se utilizó el método Delphi para crear el formulario de evaluación de riesgos. Se evaluaron posibles eventos de riesgo cuantitativamente. Se calcularon porcentajes de riesgo relativo de los sucesos de riesgo para identificar sucesos de mayor riesgo. **Resultados:** Se determinó una matriz de riesgos que contenía cuatro componentes (desastres naturales, peligros tecnológicos, peligros humanos y materiales peligrosos) y se creó un formulario de evaluación de riesgos utilizando el método Delphi. Los tres principales sucesos de alto riesgo son exposición a radiaciones internas (41%), brotes de enfermedades infecciosas (38%) e incendios internos (33%). Se elaboraron medidas de gestión de emergencias para los sucesos de alto riesgo. **Conclusiones:** El HVA basado en el modelo de Kaiser en la evaluación del riesgo de eventos en quirófano puede identificar eficazmente posibles eventos de alto riesgo, determinar prioridades de emergencia y optimizar la asignación de recursos, garantizando así la calidad y seguridad del tratamiento quirúrgico.

**Palabras clave:** Quirófanos. Evaluación de riesgos. Administración hospitalaria. Gestión de la seguridad. Catástrofes.

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## Introduction

Our hospital is one of the first batch of national tertiary Grade A women's and children's hospitals in China. As an important clinical department in our hospital, our operating room undertakes surgical procedures for the departments of gynecology, reproduction and internal secretion, obstetrics, pediatric surgery, and andrology. Our hospital's surgical volume is more than 60,000 cases/year and many of them have high complexity. In our hospital, 80% of the surgeries are at levels 3 and 4, while minimally invasive surgeries account for 83% of the total. In response to our hospital's development policy, the operating room has carried out pediatric orthopedic surgeries, urological surgeries, and da Vinci robotic surgical procedures. As the surgical teams from the plastic surgery and otorhinolaryngology departments will use the operating room, new devices will be required for surgeries, and surgical volume will increase sharply. The operating room working environment is enclosed, as exposing large quantities of blood and body fluids from surgical patients could easily cause the breeding and transmission of various pathogens. Repeated long-term usage of various apparatus and equipment makes the operating room a high-risk department when dealing with sudden hazards, while the management and clinical work of the operating room become increasingly risky and challenging.

Hazard vulnerability analysis (HVA) is an important method used to stratify the risk of potential hazardous events, measure the probability of potential hazardous events, and guide hazard preparedness and prevention<sup>1</sup>. HVA is an internationally recognized excellent method that can systematically evaluate the vulnerability of urban facilities (such as hospitals and schools) as well as the population, while comprehensively evaluating the ability of emergency medical treatment, disease prevention and treatment, and health security for injuries caused by hazard events<sup>2,3</sup>. Therefore, HVA has become an important part of emergency management in operating rooms. HVA provides scientific guidance for managers to effectively identify weaknesses in work and risk exposure in the operating room, allowing for clear focus and direction in emergency management, formulation of corresponding management strategies, enhancement of communication and cooperation between the operating room and relevant departments within the hospital, and effectively

improving the response level of operating room staff in handling high-risk events.

## Method

### *ETHICS APPROVAL*

This study was conducted in accordance with the Declaration of Helsinki. All research methods were carried out in accordance with the relevant guidelines and regulations. This study was approved by the medical ethics committee of the first author's institution. Verbal informed consent to participate in this study was obtained from all participants. The medical ethics committee of the first author's committee approved the procedure of verbal informed consent of this study.

### *Research team*

The research team was composed of 7 members. Of them, 1 possessed a doctoral degree, 4 possessed a Master's degree, and 2 possessed an undergraduate qualification; with 1 being a chief physician, 3 co-chief nurses, and 3 supervising nurses amongst the team. Their range of employment history spanned from 12 to 30 years.

### *Kaiser model-based operating room risk assessment form*

#### *INDICATOR SELECTION*

The Joint Commission International Accreditation Standards for Hospitals defines hospital HVA as the scientific identification of potential emergency situations and their possible direct and indirect impacts on a healthcare facility's running and services. The Kaiser model, developed by Kaiser Permanente Medical Group, is a tool for HVA and evaluation, with scientific and reliable results<sup>4,5</sup>. The indicator selection of risk assessment form for operating room HVA was based on the Kaiser model. Our hospital's operating room staff (including doctors, anesthetists, nurses, and nursing workers) functioned as the object of our research. A 12-month self-inspection of hidden hazards was carried out during the period of June 2021-June 2022. The risk event register was truthfully filled in, after which the research team created a summary of the data. According to the concept and connotation of hospital hazard vulnerability, the main contents of the

Kaiser model, and the actual situation of our hospital and operating room, 4 components of the operating room risk matrix were determined: namely, natural disasters, technological hazards, human hazards, and hazardous materials. Based on these 4 components, the operating room risk event register was created. Indicators of the operating room risk assessment form (including 4 level 1 indicators, and 26 level 2 indicators) were determined, and the Delphi method was used for expert consultation.

### ***EXPERT CONSULTATION QUESTIONNAIRE***

The expert consultation questionnaire contains three parts:

- Consultation description; including the research goals and significance, the description of filling in the questionnaire, and the time of expert feedback
- Consultation questions were used to evaluate the importance of each indicator according to the 5-point Likert scale: 5 points means “very important”, 4 points means “important”, 3 points means “fairly important”, 2 points means “low importance”, and 1 point means “not at all important”. An open-ended feedback column was included for the respondents to explain the added or deleted indicators
- Basic information about the experts, including a profile of them, as well as the experts’ familiarity with the research, and their self-evaluation of the basis of judgment.

### ***Expert selection***

The expert inclusion criteria, determined according to the research objective, were as follows:

- Gave informed consent to voluntarily participate in this study
- Engaged in emergency medicine and nursing, operating room nursing, operating room management, or medical education
- Working years  $\geq 10$  years
- Possessed solid theoretical knowledge and rich clinical experience, or management experience
- Possessed an undergraduate qualification or above
- Possessed a professional title at the intermediate level or above.

A total of 27 experts from 6 hospitals in Chengdu, Xi’an, and Yunnan participated in this study. The

numbers of tertiary Grade A and tertiary Grade B hospitals were 4 and 2, respectively. In terms of the experts’ professional titles: 7 possessed senior professional titles, 11 possessed deputy senior professional titles, and 9 possessed intermediate professional titles. For educational background, 7 possessed doctoral degrees, 10 possessed Master’ degrees (including 3 nurses who majored in disaster nursing), and 10 possessed undergraduate qualifications. For job content, 14 engaged in clinical work, 9 engaged in management work, and 4 engaged in education and training.

### ***Implementation of expert consultation***

The research team conducted two rounds of expert consultation through email, from February 7 to February 9, 2022. After the first round of expert consultation questionnaires were returned, the research team summarized the experts’ opinions on scores, and modifications concerning indicators. Then they added, deleted, and modified the indicators to form the second round of expert consultation questionnaire for the subsequent survey. After the second round of expert consultation, opinions reached by the experts had converged, so no other expert consultation was required. The research team modified and perfected the indicators to form the final operation room risk assessment indicators, featuring 4 level 1 indicators and 19 level 2 indicators (Table 1).

### ***HVA scoring criteria***

The scoring criteria of the Kaiser model risk assessment matrix<sup>6,7</sup> was used. It contains 7 components: likelihood of occurrence, human impact, property impact, business impact, emergency preparedness, internal response, and external response. Each indicator was set with 4 levels, demonstrated through scores ranging from 0 to 3. For likelihood of occurrence, human impact, property impact, and business impact, the highest score “3” was assigned to level 3. For emergency preparedness, internal response, and external response, the lowest score “0” was assigned to level 3.

### ***Calculate the relative risk percentage and assess the degree of hazard***

The operating room staff included in the study filled in the online operating room risk assessment form.

**Table 1. Operating room risk assessment indicators**

Level 1 indicators	Level 2 indicators
Natural disasters	Earthquake
Technological hazards	Power outages
	Water supply suspension
	Information system failure
	Internal flood
	Internal fires
	Fire alarm failure
	Medical gas failure
	Medical material supply shortage
	Explosion
	Human hazards
Infectious disease outbreaks	
Medical disputes	
Fall down/fall out of bed	
Foreign object was left in the patient's body	
Patient fainting	
Cardiac respiratory arrest occurred in the surgical patient	
Hazardous materials	Occupational exposure to human immunodeficiency virus during surgery
	Internal radiation exposure

After the forms were returned, the researchers summarized and sorted the answers. A relative risk percentage was calculated using the following formula:

$$\text{Relative risk \%} = \frac{\text{likelihood of occurrence}}{3} \times \{(\text{personal impact} + \text{property impact} + \text{business impact} + \text{emergency preparedness} + \text{internal response} + \text{external response})/18\} \%$$

The relative risk value of each high-risk event was ranked. A relative risk percentage of 0-30% is considered low risk; a relative risk percentage of 30-60% is considered medium risk; and a relative risk percentage of 60-100% is considered high risk. Fragile reinforcement should be implemented for high-risk events.

### Statistical methods

SPSS 26.0 was used for data analysis. Descriptive analysis was represented by mean, standard deviation,

coefficient of variation, and component ratio. Expert enthusiasm was expressed by the questionnaire recovery rate. A questionnaire recovery rate of > 70% was considered good enthusiasm. The degree of concentration in expert opinions was described with the mean of the importance assigned to the indicators. The degree of expert authority was expressed by the expert authority coefficient (Cr). Agreement among experts' opinions was described with Kendall's coefficient of concordance (W).

## Results

### Expert enthusiasm

Two rounds of expert consultation were carried out in this study. A total of 27 questionnaires were distributed in each round. Twenty-six and twenty-five questionnaires were returned in round 1 and round 2, respectively. All the returned questionnaires were valid, with recovery rates of 96% in round 1 and 92% in round 2. As both figures were higher than 70%, this indicates that the experts had great interest in this study, and the validity of these consulting results was high.

### Degree of expert authority (Cr)

The coefficient of expert authority is determined by two factors: the judgment coefficient (Ca) and the degree of familiarity (Cs)<sup>8</sup>. The basis of experts' judgment contains 4 aspects: work experience; theoretical analysis; reference to domestic and foreign data; and intuitive feeling. The degree of influence judged by the experts is divided into three levels: high, medium, and low, concerning frequency and relative frequency<sup>9</sup>. For experts' familiarity with the items, 0.9 indicates very familiar, 0.7 indicates somewhat familiar, 0.5 indicates neutral, 0.3 indicates a little unfamiliar, and 0.1 indicates unfamiliar.

The formula for calculating the degree of expert authority (Cr) is as follows:  $Cr = (Ca+Cs)/2$ .  $Cr \geq 0.7$  is considered good reliability<sup>10</sup>. In the first round of expert consultation, the familiarity coefficient was 0.742, the judgment coefficient was 0.900, and the authority coefficient was 0.820. In the second round of expert consultation, the familiarity coefficient was 0.820, the judgment coefficient was 0.923, and the authority coefficient was 0.825. Both of the authority coefficients in the two rounds were > 0.8, showing that

the experts had a high level of theoretical knowledge and clinical work experience on the content of the study. Therefore, this study has a high level of authority and the consulting results are reliable and effective.

**Agreement among experts’ opinions**

The agreement among experts’ opinions reflects the concentration of them and shows the consistency of experts’ judgment of various indicators. Therefore, Kendall’s coefficient of concordance (W) is an important indicator. Statistically significant differences were identified in Kendall’s coefficients of concordance in the two rounds of expert consultation ( $p < 0.01$ ), indicating a high degree of concordance of experts’ opinions (Table 2).

**HVA evaluation results and operating room risk assessment forms**

The research team distributed the online operating room risk assessment forms to 360 operating room staff included in the study. A total of 356 valid forms were returned, meaning a recovery rate of 98%. After relative risk percentages were calculated, the HVA evaluation results were obtained (Table 3). The top three high-risk events ranked by the HVA in the operating room are as follows: internal radiation exposure (41%), infectious disease outbreaks (38%), and internal fires (33%) (Fig. 1).

**Discussion**

**Significance of HVA based on Kaiser model for risk event assessment in operating room**

There is a lack of scientific tools to provide guidance for risk event assessment in the operating room, leading to managers primarily relying on their experience to conduct the assessments independently. They are more inclined to analyze the causes of the events that have occurred during work, deal with these events, and then look for corresponding improvements, but lack an understanding of prevention through assessing vulnerability. The Kaiser model can provide a scientific and efficient management tool for risk event assessment in the operating room. It integrates disaster medicine, vulnerability analysis, and nursing

**Table 2. Agreement among expert opinions**

Round of consultation	Level of indicators	Kendall’s coefficient of concordance (W)	$\chi^2$	p
Round 1	Level 1	0.012	0.533	< 0.001
	Level 2	0.276	96.350	< 0.001
Round 2	Level 1	0.059	3.953	< 0.001
	Level 2	0.184	63.022	< 0.001

emergency management organically through the risk assessment matrix, to guide managers toward identifying vulnerabilities in the system. This method, (through assessing, ranking, and identifying various potential risks in the operating room), can help distinguish the varying levels of vulnerability to different risks in the system<sup>11</sup>. Moreover, it can also enable managers to assess which are the most risky, most likely, and most serious events in the operating room emergency system. This in turn, will allow managers to take measures to prioritize solutions, strengthen emergency drills for these risk events, improve response efficiency, and ensure the supply of materials.

**Significance of HVA using Kaiser model for emergency management in operating room**

HVA can be divided into pre-assessment and post-assessment. Pre-assessment emphasizes feed-forward control of events, effective prediction and objective evaluation of risk events, and carrying out emergency drills to reduce the incidence. The Ministry of Health of China<sup>12</sup> clearly proposed in the hospital grade evaluation that HVA should be incorporated into the establishment and improvement of hospital emergency management systems. The Kaiser model is widely used in hospital management, especially in quantitative risk assessment. In 2017, the California Hospital Association updated the Kaiser model<sup>13</sup> by adding content relating to early warning events, and the number of effective actions, so as to present the emergency management of the organization in a more comprehensive way.

Using the Kaiser model-based HVA to assess risk events is to identify the most significant problems of vulnerability in the entire operating room system, so as to guide managers toward analyzing and preventing

Table 3. Hazard vulnerability analysis in the operation room

Hazardous events	Probability			Severity				Relative risk	Rank
	Likelihood of occurrence	Human impact	Property impact	Business impact	Emergency preparedness	Internal response	External response		
Assessment criteria	Injury or death in medical staff	Property losses and damages	Interruption of healthcare services	Emergency pre-planning and drills	Time, effectiveness, and resources	Social support to the hospital			
	0 = None / Not applicable 1 = Low 2 = Medium 3 = High	0 = None / Not applicable 1 = Low 2 = Medium 3 = High	0 = None / Not applicable 1 = Low 2 = Medium 3 = High	0 = None / Not applicable 1 = High 2 = Medium 3 = Low/None	0 = None / Not applicable 1 = High 2 = Medium 3 = Low/None	0 = None / Not applicable 1 = High 2 = Medium 3 = Low / None			
Natural disasters									
Earthquake	1.09	1.42	1.45	1.74	2.73	2.24	1.48	0.22	16
Technological hazards									
Power outages	1.50	1.09	0.80	1.94	0.97	1.80	3.14	0.27	9
Water supply suspension	1.62	1.09	0.80	1.67	1.29	2.11	3.14	0.30	7
Information system failure	1.92	0.73	0.95	1.68	1.94	1.03	2.26	0.31	4
Internal flood	1.26	2.42	2.70	2.88	1.47	1.41	2.45	0.31	4
Internal fires	1.56	1.76	2.59	2.39	1.24	1.18	2.42	0.33	3
Fire alarm failure	1.11	2.65	2.97	2.42	1.55	2.35	2.98	0.31	4
Medical gas failure	1.30	1.39	1.98	1.59	1.38	1.77	2.82	0.26	11
Medical material supply shortage	1.18	0.59	1.15	2.55	1.56	2.45	2.39	0.23	13
Explosion	1.17	1.89	1.89	2.38	1.68	1.85	1.32	0.24	12
Human hazards									
Drunk or armed intruders	0.42	1.55	1.65	1.68	0.73	0.73	0.85	0.06	19
Infectious disease outbreaks	1.71	2.74	2.36	2.17	1.09	1.56	2.08	0.38	2
Medical disputes	1.41	1.67	1.82	1.74	1.97	1.97	2.08	0.29	8
Fall down/fall out of bed	1.21	0.00	1.73	1.88	1.68	1.86	3.20	0.23	13
Foreign object was left in the patient's body	1.17	0.95	1.85	2.83	1.21	1.35	2.27	0.23	13
Patient fainting	1.50	0.41	0.98	2.21	1.73	1.62	2.82	0.27	9
Cardiac respiratory arrest occurred in the surgical patient	1.17	0.11	0.94	2.53	0.88	1.09	2.39	0.17	18
Occupational exposure to human immunodeficiency virus during surgery	0.83	2.98	2.08	2.42	1.29	1.06	1.97	0.18	17
Hazardous materials									
Internal radiation exposure	1.88	2.83	2.05	2.21	1.20	1.30	2.27	0.41	1

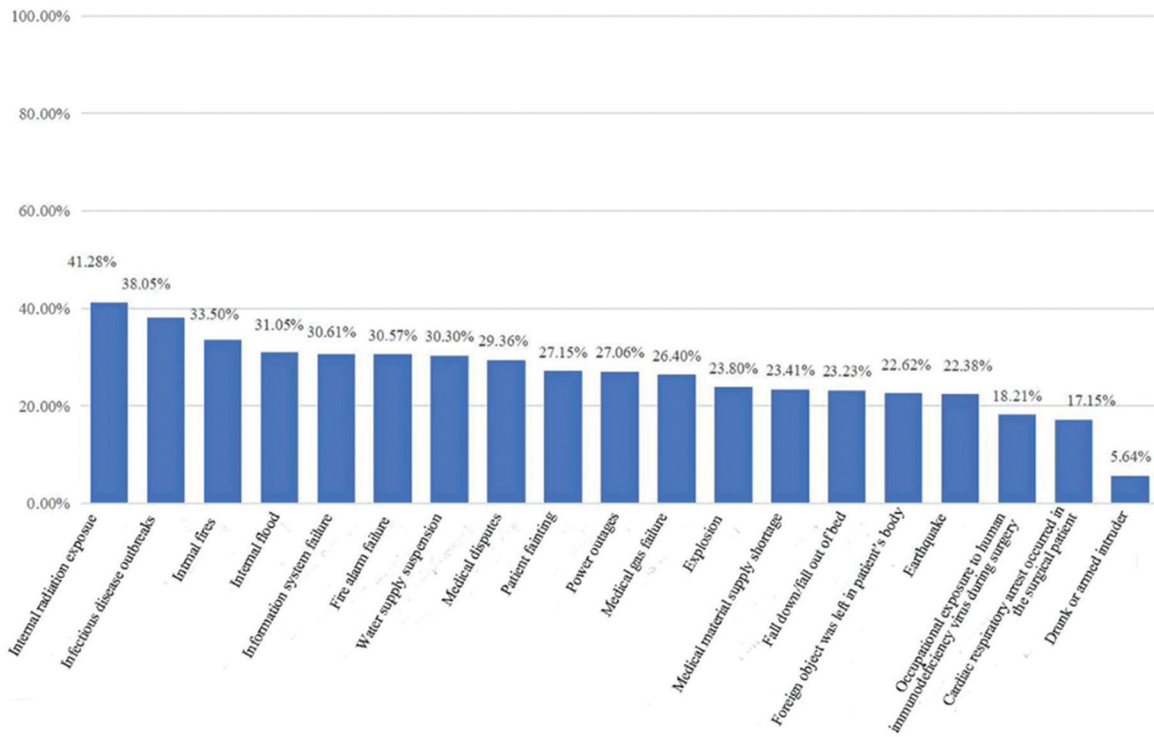


Figure 1. Rank of relative risk percentages of events in the operation room.

risk events, while clarifying the emergency management's direction for continuous improvement. Through the 19 listed risk events in the operating room, the managers can analyze the reasons and formulate countermeasures for the top three high-risk events, avoiding the blindness of emergency management.

### **Risk of internal radiation exposure**

Our hospital is a specialized hospital for women and children, thus the majority of the surgeries carried out before our study were limited to gynecology, obstetrics, and reproductive endocrinology. With the integration of the medical market and the broadening of our hospital's development ideas and directions, surgical specialties have expanded to pediatric orthopedic surgeries and interventional surgeries carried out by radiation equipment. However, the original operating room facilities cannot meet the protection requirements of these surgeries, and the operating room staff lacks the relevant protection awareness, knowledge, and skills. In addition, due to the special environment in the operating room and the long working hours of operating room staff, management mistakes or protection loopholes when dealing with radioactive substances may lead to

negative health impacts on operating room staff, and cause certain public hazards<sup>14</sup>. Therefore, due to the imperfect protection management and the great harm of radioactive material exposure, internal radiation exposure became the highest risk event in the operating room.

### **Risk of infectious disease outbreaks**

As an important place for disease diagnosis, treatment, and first aid, the operating room also takes on important responsibilities during the outbreak of infectious diseases. Due to the enclosed surgical environment and the particularity of surgical methods, infected persons can become infection sources. Exposed blood, body fluids, and respiratory tracts become the main transmission medium, while aerosol transmission also exists in the enclosed environment. Epidemic outbreaks are sudden, urgent, and uncertain, making operating room work more risky and difficult to respond to.

### **Risk of internal fires**

There are 62 operating rooms in our hospital, covering an area of more than 5,000 square meters, and the

annual operation volume reaches more than 20,000 cases. Every operating room is equipped with an endoscopic surgery system, various kinds of electrosurgical equipment, an information management system, an intelligent material management system, etc. A large number of electrical instruments and equipment run for extensive periods of time, and the daily average flow rate of nearly 1,000 people brings great challenges to operating room fire safety management. Once a fire occurs, the safety of patients and staff, along with the protection of large valuable assets of the hospital, becomes at risk.

### ***Improve the operating room risk emergency management mechanism***

It is necessary to establish an operating room risk management team composed of the director of anesthesia, the head nurse, the surgical team leader, and the person in charge of operation management. The management team shall formulate detailed work plans and contents, clarify the job responsibilities of each member, prepare the quality and evaluation criteria of clinical work, get familiar with the risk management process, monitor all steps in surgeries, and start all necessary emergency preparedness plans at times when vulnerable links are found.

### ***Improve the risk management system and optimize the risk management process***

The risk management team regularly revises and improves the management and working systems in the operating room, and annually formulates risk management plans, emergency preparedness plans, specialized training plans, assessment plans, emergency drill plans, etc., based on vulnerability analysis and risk event assessment. It is advisable to optimize workflows, smooth the reporting channels of risk and defect events, smooth the communication and coordination channels between the operating room and other departments, and facilitate the timely collection of feedback on the treatment and effect of risk events.

### ***Raise our awareness of risk management and strengthen our ability to cope with risks***

It is advisable to strengthen the relevant training of risk management for operating room staff and improve the risk management awareness of each staff member so that they can have a sharpened insight into potential

risks. Through specialized training and emergency drills, the staff can learn to strictly abide by the rules and regulations, strictly implement work procedures, and gain relevant coping abilities for facing potential risk events.

## **Conclusions**

The Kaiser model is a concise, applicable, scientific and effective HVA tool, and has strong applicability to the assessment of risk events in the operating room. Medical institutions, especially operating rooms, have dynamic changes in operating room risks due to the severity of surgical treatment, complexity of instruments and equipment, diversity of personnel, and their enclosed environment. Only by using scientific management tools and regularly identifying and evaluating risks, we can effectively control the vulnerable links in operating room management. This should mean: constantly implementing fragile reinforcement, strengthening emergency management abilities, improving medical quality, and guaranteeing the safety of operating room staff and patients.

## **Ethics approval**

All procedures of this study were performed in compliance with relevant laws and institutional guidelines and have been approved by the Medical Ethics Committee of West China Second University Hospital, Sichuan University (2023 Medical Scientific Research for Ethical Approval No. [054]).

## **Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## **Funding**

The authors declare that they have not received funding.

## **Conflicts of interest**

The authors declare no conflicts of interest.

## **Ethical considerations**

**Protection of human and animal subjects.** The authors declare that the procedures followed complied with the ethical standards of the responsible human

experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki. The procedures were approved by the institutional Ethics Committee.

**Confidentiality, informed consent, and ethical approval.** The study does not involve patient personal data nor requires ethical approval. The SAGER guidelines do not apply.

**Use of artificial intelligence for generating text.** The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

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