johb.info



Review Article

One Health Bulletin

Enhancing vaccination of key populations: Lessons and actions

Jinsong Zhang[1,2,3#], Zaihong Li[4#], Jiahai Lu[1,2,3,5,6✉], Zeliang Chen[1,2,3,7✉]

[1]*One Health Centerof Excellence for Research and Training, School of Public Health, Sun Yat-sen University, Guangzhou 510080, China*

[2]*NMPA Key Laboratory for Quality Monitoring and Evaluation of Vaccines and Biological Products, Guangzhou 510080, China*

[3]*Key Laboratory of Tropical Diseases Control, Sun Yat-Sen University, Ministry of Education, Guangzhou 510080, China*

[4]*Hainan Women and Children's Medical Center (Women and Children's Health Care Center of Hainan Province, Hainan Children's Hospital, Children's Hospital of Fudan University at Hainan, Hainan Obstetrics and Gynecology Hospital), Haikou 571100, China*

[5]*Research Institute of Sun Yat-Sen University in Shenzhen, Shenzhen 518057, China*

[6]*Hainan Key Novel Thinktank "Hainan Medical University 'One Health' Research Center", Haikou 571199, China*

[7]*Key Laboratory of Zoonose Prevention and Control at Universities of Inner Mongolia Autonomous Region, Medical College, Inner Mongolia Minzu University, Tongliao 028000, China*

ABSTRACT

Vaccination is effective in preventing the increase of disease, especially emerging infectious diseases (EIDs), and it is particularly important for people in close contact with infected sources and susceptible populations who are at increased risk of getting infectious diseases due to behavior, occupation or health. Despite targeted vaccination guidelines, inadequate vaccination of the key populations fails to receive widespread attention, resulting in a high-risk transition of disease from key populations to general populations. Strengthening the vaccination of the susceptible groups can effectively block the spread of pathogens to general populations, and reduce the consumption of medical resources in universal vaccination, which has significant economic value. In this review, we describe the prevalence of EIDs, analyze the experience and lessons of infectious disease vaccination in key populations through several cases, and further explore the causes for the decline in vaccination rates of key populations. According to the trends of EIDs, a plan to strengthen the vaccination of key populations is proposed to effectively prevent the transition of EIDs from key populations to general populations.

KEYWORDS: Key populations; Emerging infectious diseases; Vaccination; Future

1. Introduction

Vaccinations are proven to play an important role in preventing and controlling many infectious diseases. In the 21st century, however, vaccination programs face multiple challenges[1]. On the one hand, effective and safe vaccines against new (re)emerging pathogens need to be developed rapidly. For example, coronavirus disease 2019 (COVID-19), the ongoing pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is an example of a much-needed vaccination that may reduce the huge impact of its current pandemic[2]. On the other hand, there is a huge challenge brought about by the decline in vaccination rates, especially in key populations, which may directly lead to the transition of EIDs from key populations to general populations in the future. For example, measles cases have increased by as much as 300% over the past few years. The main reason is that parental rejection of universal immunization plan prevents their children from being effectively vaccinated, resulting in an increased incidence of the disease in children, a high-risk group[3].

Key groups are those at increased risk of infectious diseases due to their behavior, occupation or health. In this paper, they are divided into two groups: 1) groups of people in close contact with infected sources; 2) susceptible groups. Among them, people in close contact with infected sources are those who are at increased risk of disease

#These authors contributed equally to this work.

✉To whom correspondence may be addressed. E-mail: lujiahai@mail.sysu.edu.cn; chenzliang5@mail.sysu.edu.cn

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-Non Commercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: reprints@medknow.com

©2022 *One Health Bulletin* Produced by Wolters Kluwer- Medknow.

How to cite this article: Zhang JS, Li ZH, Lu JH, Chen ZL. Enhancing vaccination of key populations: Lessons and actions. One Health Bull 2022; 2; 16. https://www.doi.org/10.4103/2773-0344.361972

Article history: Received 6 September 2022 Revision 20 October 2022 Accepted 28 October 2022 Available online 29 November 2022

due to behavioral or occupational exposure to infectious agents or pathogens, and these people were further divided into three groups, including occupational groups, travelers, and health care workers. The susceptible population is defined as a population who is easily infected on account of lack of specific immunity to a certain infectious disease due to their own health status. The population is also divided into three groups, including children and the elderly, immunocompromised patients, and people who have lesions in the body that make them susceptible to an infectious disease.

In the future, the prevalence of EIDs will tend to develop towards the development of insect-borne infectious diseases, zoonotic infectious diseases and natural foci diseases mainly spreading in forestry and animal husbandry areas. Unfortunately, as global vaccination rates have declined in recent years, vaccination of key populations has been unsatisfactory. There are numerous cases of socioeconomic losses from infectious disease outbreaks due to failure to vaccinate key populations. Hepatitis E virus (HEV) seroprevalence is strongly associated with direct animal contact. Butchers, abattoir workers, veterinarians, farmers, hunters and forestry workers are considered at risk of HEV infection. Low vaccination rates in this population have resulted in 20 million new events of HEV infection, 3.3 million symptomatic cases, and 44 000 deaths annually[4]. Therefore, it is of great significance to strengthen the vaccination of key populations, formulate appropriate vaccination guidelines and strategies according to different types of groups, to prevent the spread of new infectious diseases from key populations to general populations in the future.

In this article we describe the epidemic status of EIDs, and analyze the experience and lessons of infectious disease vaccination in key populations through several cases, and further explore the reasons for the decline in vaccination rates. Finally, we put forward recommendations to strengthen the vaccination of key groups according to the future direction of EIDs.

2. Epidemiological status of EIDs

2.1 Popularity of EIDs

EIDs are defined as infectious diseases that are newly identified or already present in the population but are rapidly increasing in incidence or geographic extent[5]. New infections account for at least 15% of all human pathogens, according to the 10th EID International Conference[6–7]. In contrast to other human diseases, infectious diseases can be unpredictable and h ave the potential for global outbreaks. Historically, the global burden of disease has been disproportionately borne by vulnerable countries in Africa, South America and Asia. In particular, EIDs mainly affect underdeveloped countries. Parasitic diseases such as malaria, hookworm and schistosomiasis and bacterial diseases including *Mycobacterium tuberculosis* and *Chlamydia trachomatis* affect a large portion of the world's population and have become the focus of disease attention. In the past 20 years, several landmark events have occurred in the field of infectious diseases with epidemic potential including SARS (Severe Acute Respiratory Syndrome) pandemic (2002-2004), Ebola virus disease outbreak in West Africa (2013-2016), Yemen cholera outbreak (2015-2018), Zika virus in the Americas and Southeast Asia (2016-2018), Lassa fever in Nigeria (2018), diphtheria in Venezuela (2016-2017) and Yemen (2017-2018), yellow fever in Latin America and Africa (2016-2018), India and Nipah virus in South Asia (2017-2018), and the currently unfolding SARS-CoV-2 (new coronavirus) pandemic (2019-present). The following table lists a series of EIDs that will or have threatened global health security, providing a certain direction for the precise prevention and control of EIDs in the future (Table 1).

Table 1. Major types of diseases.

Viral diseases
COVID-19
Severe acute respiratory syndrome*
Middle East respiratory syndrome*
Influenza
Ebola*
Marburg*
Viral hemorrhagic fevers (including Crimean-Congo hemorrhagic fever*)
Rift Valley fever*
Lassa fever*
Dengue
West Nile fever
Polio (wild-type polio virus)
Zika*
Chikungunya*
Nipah and henipavirus diseases*
Yellow fever
Viral hepatitis
Monkeypox
Bacterial diseases
Tuberculosis*
Invasive pneumococcal disease
Invasive meningococcal disease
Diphtheria
Typhoid
Cholera
Pertussis (whooping cough)
Others
Drug-resistant malaria
Antiretroviral-resistant human immunodeficiency virus/AIDS
Disease X: unknown emerging pathogens
Drug-resistant bacterial, viral, and protozoal infections

* WHO Blueprint priority disease

2.2 Vaccination in the control of EIDs

Infectious diseases are transmissible, but it is possible to develop immunity to reinfection. Many infectious diseases can be prevented by vaccines with potential eradication. Worldwide attention is now turning to vaccine missions against these emerging and re-emerging pathogens. There is renewed interest and support from international governments, the WHO and institutions such as the Alliance for Epidemic Preparedness Innovations. Philanthropic organizations such as the Global Alliance for Vaccines and

Immunization and the Gates Foundation are currently making progress in the development of diagnostics, treatments and vaccines for EIDs. Effective vaccination stops the spread of viral diseases. In a study conducted in Israel, the SARS-Cov-2 viral load in the nasal mucosa samples of healthcare workers was assessed weekly. The viral load of vaccinated people was 2-4 times lower than in unvaccinated people[8]. During the 2014 EBOV outbreak, the rVSV-EBOV vaccine developed by Merck made the most progress and was used to stop the outbreak in the Democratic Republic of Congo. The second vaccine involves a strategy using Ad26 and MVA vector components developed by Janssen Pharmaceuticals and is currently being deployed in the Congo epidemic[9].

3. Vaccination cases for key populations

3.1 COVID–19 among seafood processing workers in Alaska: Implications for preventive measures

COVID-19 outbreaks in high-density workplaces such as food processing facilities[10]. Alaska's seafood processing industry attracts approximately 18 000 out-of-state workers annually[11]. Many of the state's seafood processing facilities are located in remote areas with limited healthcare capacity. With 13 outbreaks of COVID-19 at seafood processing facilities and processing ships as of September 2020, the Centers for Disease Control and Prevention (CDC) personnel in Alaska have identified a link between seafood processing and disease transmission by reviewing survey data for laboratory-confirmed SARS-CoV-2 in the state. A total of 677 cases of SARS-CoV-2 infection were identified, most of which were associated with interstate transmission, which has attracted great attention from the local government and the health department[11].

On March 23, 2020, the Governor of Alaska issued a COVID-19 health directive HM10 to address health concerns related to the impending influx of workers during COVID-19 pandemic, which requires employers to bring critical infrastructure (essential) into Alaska to submit a Community Workforce Protection Plan[12]. On May 15, 2020, the mandate added specific requirements for seafood processors to reduce the risk of SARS-CoV-2 transmission in these high-density workplaces[13]. The requirements include measures to prevent introduction of SARS-CoV-2 into the workplace, detect new workers, and to set a 14-day entry quarantine before workers enter non-isolated dwellings. Requirements were further revised in November 2020 to include vaccination of key groups (seafood processors and workers) into the health directive to achieve high levels of vaccination coverage[14]. The COVID-19 outbreak in the state has been further effectively controlled following enhanced vaccination strategies among key groups, interrupting the potential for transmission of the virus from high-risk groups to the general populations.

3.2 China's vaccination program: An effective way to prevent HBV in susceptible groups

Hepatitis B virus (HBV) causes approximately 240 million chronic infections and 780 000 deaths annually from cirrhosis and liver cancer[15]. Recognizing the huge global disease burden, the United Nations has included the fight against hepatitis in the 2030 Sustainable Development Goals. HBV is highly prevalent in China, and serological surveys in 1979 and 1992 indicated a prevalence of HBV surface antigen (HBsAg) of 10%[16–17]. Based on these two surveys, it is estimated that 120 million people carry HBsAg[18–20], 20 million people suffer from chronic hepatitis B, and nearly 300 000 people die each year as a result of the chronic consequences of HBV infection in China. Liver cancer and cirrhosis are both among the top 10 most common causes of death in China. HBV causes most deaths[21–23], and the high rate of chronic HBV infection in infants suggests that infection occurs in early childhood[24–26].

In order to control HBV, the Chinese government has made HBV vaccines a top priority for infant vaccination. The implementation of China's immunization strategy began with the licensing of plasma HBV vaccine in 1985. In 1992, the Ministry of Health recommended HBV vaccine for routine immunization of infants, but parents need to purchase the vaccine by themselves. In 1999, the National Expanded Programme on Immunization (EPI) review showed that immunization coverage with three doses of HBV vaccine was 70.7%, but ranged from 99% in Beijing to 7.8% in Tibet[27]. A follow-up survey showed that immunization coverage for children born in 2001 had reached 82.4%, but disparities remained in western provinces and rural areas[28]. In 2002, China included HBV vaccine in the EPI, providing free vaccine to children under 14 years old[29–30]. In addition, the Global Alliance for Vaccines and Immunisation (GAVI) project provided US$ 76 million to purchase HBV vaccine and auto-disabled syringes for all children born in western provinces and central poor counties[31]. In order to speed up the prevention and treatment HBV, the Ministry of Health has formulated the "2006-2010 National Hepatitis B Prevention and Control Guidelines", and established the national goal of achieving a national HBsAg prevalence rate of less than 7% and children under five years old less than 1% by 2010[32]. In 2009-2011, China launched a HBV catch-up campaign targeting children under the age of 15 years old born in 1994-2001, which vaccinated about 68 million children against HBV. Compared with pre-vaccination, chronic HBV infections in children under age 15 years old in China decreased by 90% (from 10.5% to 0.8%) and children under age five years old by 97%(from 9.9% to 0.3%). By 2014, regional and urban-rural differences between young children in 1992 and 2006 had been largely eliminated. The prevalence of HBsAg in young children was lower in 2014 (0.1%) compared to 2006 (0.3%). The vaccination program in China is considered to be a successful case of HBV prevention through universal infant vaccination[32].

3.3 Challenges for U.S. HCPs in COVID–19 Vaccination

Health care professionals (HCPs) are defined by CDC as "persons serving in a health care facility who have the potential to be in direct or indirect contact with patients or infectious materials" including doctors, nurses, interns, and non-clinical essential workers, who have been prioritized for COVID-19 vaccination[33]. This prioritization is reflected in multiple vaccine distribution plans developed by public health professionals and bioethicists. But distributing a COVID-19 vaccine among HCPs has proven to be a major challenge, especially in the U.S.[34–35]. Few data are available on vaccination against COVID-19 among HCPs in occupational groups in the U.S., in contrast to a recently published figure in the U.K. that showed vaccination rates of over 80% for all occupational groups[36].

Multiple factors contribute to the extremely low vaccination rates of HCPs in the U.S., including disorganized distribution campaigns, vaccine hesitancy and inequity[37–38], fragmented healthcare, and chaotic policies across states and other jurisdictions. Inequity in vaccine distribution and vaccine hesitancy are important reasons for the decline in HCPs vaccination rates. Many frontline HCPs have successfully vaccinated in prestigious medical institutions such as academic affiliated hospitals in the U.S.[39]. Significant differences emerged between HCPs in the same category but in different locations. For example, some medical students in the U.S. are able to be vaccinated, while others who work in different departments or locations are not[40]. As a key group with close contact with pathogens, HCPs should be more vaccinated, which may be an important factor leading to frequent nosocomial infections in various regions of the U.S.

3.4 Reason analysis for the decline of vaccination rate in key populations

3.4.1 Healthcare Workers

Healthcare Workers (HCWs) are a critical group of professionals who are exposed to biological risks during their work activities from exposure to potentially infected patients and materials. Vaccination is the most important strategy for primary prevention. In some cases, when a disease can be transmitted by humans, such as influenza or HBV, vaccines can protect not only HCWs, but also colleagues and patients to whom she/he may transmit the infection[41–42]. However, the vaccination rate of HCWs is unsatisfactory[43–45].

Numerous studies have shown that the lack of knowledge of HCWs on infection risk and the benefits of vaccination is the primary reason[46–47]. HCWs realize that they are particularly vulnerable to vaccine-preventable diseases and can play a role in nosocomial transmission, which make them become an important target group for vaccination[48]. Examples of poor knowledge of healthcare workers and vaccinations are reported in many literatures. In a recent Italian flu study, Albano *et al*. found that HCWs did not fully understand how the disease was transmitted[49]. Meanwhile, vaccination against measles, mumps, rubella and chickenpox, which are critical for susceptible HCWs, has received little attention[50–53]. For instance, there is a low pertussis vaccination rates among HCWs[54]. The above examples indicate that medical workers do not have a good understanding of the risk of infectious disease. Furthermore, it needs to be taken into account that many countries have immunization recommendations for healthcare workers, but no universal policy exists. There is a lack of homogeneity across countries in terms of vaccine types, schedules, implementation frameworks (recommended or mandatory), and target categories for HCWs[55].

3.4.2 High–risk occupational groups other than HCWs

Given the diversity and complexity of occupational types, there is no universal vaccination policy for occupational groups currently. However, many studies have shown that the vaccination rate of occupational groups, especially those exposed to pathogens with risk of transmission, is not high. This significantly increases the incidence of infectious diseases in the occupational population, leading to severe staff shortages and ultimately economic losses. For example, a meta-analysis of 28 studies from mainland China showed that occupational contacts (pig farmers, slaughterhouses, pig vendors and veterinarians) had a 2.63-fold higher risk of HEV IgG seropositivity than the general population[56]. However, due to the low vaccination rate, frequent outbreaks and epidemics of HEV among occupational populations in various regions have brought a huge burden to the health care system and socioeconomics.

By reviewing relevant literatures, the main factors leading to the low vaccination rate of occupational population were analyzed. Among them, occupational groups, especially high-risk occupational groups vulnerable to infectious diseases, have low awareness of occupational infection risks, which is directly related to the lack of health education on vaccination by employers. For example, a study by Liu Wei *et al*. on the vaccine awareness and vaccination willingness of hepatitis E-related occupational groups found that 77.7% of the occupational groups in the surveyed population were not aware of the harm of hepatitis E and up to 62.1% of the population are unaware of hepatitis E vaccination[57]. At the same time, a study by Wang Quanyi *et al*. on the knowledge, belief and behavior of viral hepatitis among pig-related occupationally exposed people in Beijing found that the hepatitis B vaccination rate of pig-related occupationally exposed people was 29.55%[58]. Among them, the main reasons for not vaccinating hepatitis B are the low awareness of basic knowledge of viral hepatitis, and the belief that not vaccinating can also play a preventive effect on the premise of paying attention to personal hygiene.

3.4.3 Travelers

Travelers are at risk because they may be exposed to infectious diseases they have never encountered before at their destinations. Travelers who are not properly vaccinated on their trips are at risk of illness, causing a public health concern for infectious diseases concurrently, as they may carry infections home to the general populations[59]. For travelers, low perceived risk of infection and awareness of vaccination recommendations are the main reasons for unsatisfying vaccination rates. In multiple studies, 13% to 73% of travelers were unaware of vaccination availability (or unawareness of vaccination recommendations), which contributed to delays in

vaccination in this group[60–63].

A classic study by Mark R Duffy *et al*. found that only 11% of 415 travelers with a high risk of Japanese encephalitis virus reported receiving one dose of Japanese encephalitis vaccine, while up to 69% of 164 high-risk travelers who were not vaccinated against Japanese encephalitis virus said they had never heard of this vaccine or that their healthcare provider did not offer or recommend it[64]. In another study, the use of the recommended vaccine for serious bacterial infections was low among Australian pilgrims[65]. Lack of awareness of vaccine availability, misunderstandings about vaccine safety, and high cost are the major barriers to vaccination.

3.4.4 Susceptible groups

People who lack specific immunity to infectious pathogens are susceptible to infection. If there are many susceptible persons in the population, the susceptibility of the population is high. Without timely vaccination, epidemic of infectious diseases tend to occur. This article specifically divides susceptible groups into children and the elderly, immunocompromised patients, and those with physical lesions that make them susceptible to certain infectious diseases. For susceptible populations, the main reasons for low vaccination rates are mainly due to their ignorance of the recommended type of vaccination, focus on the risks of vaccination and fear of worsening potential disease. One study reported that more than 10% of unvaccinated immunocompromised patients were unsure how to schedule vaccination[66]. In another study, inflammatory bowel disease population expressed concerns about the safety and efficacy of vaccines, particularly influenza vaccination, which may result from the compromised state of the patient's immune system[67–68]. General negative attitudes towards vaccination due to fear of vaccination risks have also been described in childhood vaccination decision[69]. The decline in vaccination rates among elder adults has been reported in several studies due to concerns about side effects following vaccination and fears of worsening of the underlying disease.

4. EIDs in the future

4.1 New features of EIDs

4.1.1 Viral pathogens become mainstream

In recent years, among the infectious diseases classified as public health emergencies by WHO, the proportion of viral pathogens is increasing. Compared with bacterial pathogens, viral pathogens have the following characteristics. First, there are many types of viral pathogens. According to the statistics of the International Committee on Taxonomy of Viruses, there are nearly 5000 types of viruses known in the world and many subtypes of viruses under each type[70]. Scientists estimate that there are about 30-50 million types, of which at least 32000 species can infect mammals. Second, viral pathogens mutate quickly. The natural mutation rate of virus replication can reach 10-5 to 10-8. Third, the reorganization rate of viral pathogens is high. Experts speculate that worldwide influenza pandemics, which occur every ten years or so, may be caused by genetic recombination of human influenza viruses with influenza viruses from certain animals, such as chickens, horses and pigs[71–72]. Fourth, humans lack immunity and specific medicines to viruses, which makes the prevention and targeted treatment of viral pathogens even more difficult.

4.1.2 Characteristics of zoonosis

Each specific virus has its own host of infection, including animals, plants and native species. Zoonotic disease accounts for approximately 60% of all known infectious disease and 75% of EIDs[73]. According to the U.S. Centers for Disease Control and Prevention, animal diseases account for five of the six major organisms causing national security crises, including anthrax, botulism, plague, tularemia and viral hemorrhagic fever[74]. The characteristics of zoonosis have greatly expanded the infection route of infectious diseases, increased the risk of human infection and the difficulty of prevention and control.

4.1.3 Transmission among key populations

Due to the low immunity of susceptible people in key populations, it is difficult to resist the attack of viral pathogens characterized by variety and rapid variation in the future. For example, the morbidity and mortality of COVID-19 in susceptible populations (including children, the elderly and patients with functional defects or diseases of their own lungs) are much higher than those of ordinary adults[75–78]. At the same time, closely exposed groups in key populations have increased exposure to infectious agents (or pathogens) due to behavior or occupation. In particular, the EIDs mainly transmitted by zoonosis in the future will greatly increase the risk of disease for personnel engaged in related occupations. Butchers, slaughterhouse workers, veterinarians, farmers, hunters and forestry workers are considered risk groups for HEV infection. There are 20 million new events of HEV infection with 3.3 million symptomatic cases and 44000 deaths annually[79]. Similarly, Su *et al*. explained that workers who come into contact with animals, especially livestock and/or poultry, are at risk of contracting zoonotic diseases[80]. And Haagsma *et al*. identified farmers, slaughterhouse workers, animal care workers, veterinarians, hunters and gardeners as people at risk of contracting zoonotic diseases after contact with animals[81].

4.2 Trend of EIDs in the future

4.2.1 Zoonotic EIDs

In recent years, the frequency of international outbreaks of novel and severe infectious diseases has greatly accelerated. Among them, a variety of zoonotic pathogens such as West Nile virus, Marburg virus, Lassa virus, Venezuelan equine encephalitis virus, Nipah virus, Trypanosoma brucei and Rift Valley fever virus have caused human or animal disease larger outbreaks.

4.2.2 Insect–borne EIDs

Arthropods can transmit pathogens in the process of feeding on the blood of vertebrate hosts, causing insect-borne diseases. In recent decades, some new insect-borne diseases have been discovered

around the world, and other traditional diseases that spread to new areas due to population movement and the expansion of vector habitats, causing re-epidemics and emerging as new public health threats. Natural and social factors such as climate change, urbanization, land reclamation, population growth, changing lifestyles and easy transportation are driving their spread. Among them, West Nile virus, Zika virus, Chikungunya virus, Rift Valley fever virus, Crimean-Congo hemorrhagic fever virus, Bowassan virus and Bourbon virus, etc., are all newly emerged arboviruses in recent years.

5. Strengthening key groups vaccinations

5.1 Develop vaccination guidelines for different key groups

There are differences in the types of vaccination, vaccination methods, vaccination doses and adverse effects after vaccination for different key populations. Targeted vaccination guidelines should be formulated according to the types of key populations and the actual situation.

5.2 Make it clear that government is leading and medical departments cooperate with each other

In recent years, One Health has become an internationally recognized key strategy to address major and complex human health issues. On April 21-22, 2021, the 697th Xiangshan Science Conference co-chaired by Fu Gao *et al.* was held in Beijing with the theme of "One Health and human health" aiming to better integrate the One Health concept into healthcare policies and to build a strong public health system[82]. In the process of formulating and implementing vaccination programs for key groups, the government should establish a dominant position, and health departments, medical institutions and third-party testing institutions should play an active role in cooperation, which is an important manifestation of the practice for One Health concept.

5.3 Carry out targeted publicity to improve awareness rate of vaccination

Internet, radio, television and other media should be fully utilized to popularize the immunization knowledge of key groups. Employers actively organize activities related to vaccination educational materials, educational meetings, and reminders and rewards for key population groups.

5.4 Make full use of information management to standardize management of key populations

In the era of big data, government departments are confronting common problems, including unsharable resources, poor information communication and difficult business collaboration[82]. These problems can be attributed to inadequate data sharing. Establish a vaccination information management system for key population groups to achieve information sharing, which is used to query and understand the inoculation information of key population, in order to realize continuous management and avoid false inoculations. At the same time, the basic information of key populations will be included in the management system to facilitate later vaccination.

5.5 Strengthen the management of grass-roots preventive healthcare work

Areas with poor medical and health facilities such as remote mountainous and rural areas should pay more attention to the vaccination of key groups. On the one hand, to improve the level of preventive health care at the grass-roots level is to strictly enforce the management system of preventive staff and continuously improve the quality of preventive vaccination personnel. On the other hand, it is necessary to establish and improve vaccination information files for key grass-roots groups and migrating populations, and register vaccination information in a timely manner. At the same time, follow-up vaccination management should be done to ensure the continuity of management.

5.6 Develop new technology for infection diagnosis and detection

To contain infectious epidemics, a collaborative approach involving accurate diagnosis, epidemiology, surveillance and prevention is essential. And proper diagnosis using rapid techniques plays a vital role. Among them, RT-PCR is the gold standard for pathogen detection, but the scheme is limited by the detection time and location. The development of high-sensitivity and high-specificity antibody rapid diagnostic method is of great significance for rapid and accurate detection. The specific antibodies can be used for the diagnosis and treatment of infectious diseases in key populations.

5.7 Provide free vaccines

Inequities in the vaccine distribution system and high prices are important factors leading to the decline in vaccination rates. Governments should establish a sound and fair vaccine distribution system, and provide free vaccines to key groups as much as possible to reduce the economic burden and effectively increase the vaccination rate.

6. Conclusions

In this review, we explore the reasons and strategies for enhancing vaccination of key populations in the future. The lack of knowledge on infection risks and benefits of vaccination is the main reason of HCWs of low vaccination rates; occupational groups, especially high-risk occupational groups vulnerable to infectious diseases, have low awareness of occupational infection risks, which is directly related to the lack of health education on vaccination by employers;

the low awareness of occupational infection risks is the main reason for occupational groups of low vaccination rates, especially high-risk occupational groups that are vulnerable to infectious diseases, which is directly related to the lack of health education on vaccination by employers; for closely exposed populations, who are often unaware of the type of vaccination recommended and are primarily concerned with the risks of vaccination and fear of worsening of the underlying disease are the main reasons for the low vaccination rates. We further analyze the new characteristics and epidemic trends of EIDs, and insect-borne infectious diseases and zoonotic diseases will become the key prevention and control directions of infectious diseases in the future. Given that most types of EIDs have key populations that are susceptible to exposure and infection, we put forward a targeted plan to strengthen the vaccination of key populations to effectively organize the transition of EIDs from key populations to the general populations. This review is the first to comprehensively analyze the direction and strategy of vaccination of key populations from the perspective of future EIDs, and provide important theoretical support for the prevention and control of EIDs among key populationsin the future.

Disclaimer

The authors contributed to this article in their personal capacity. The views expressed are their own and do not necessarily represent the view of the institutions they are affiliated with.

Conflict of interest statement

The authors claim there is no conflict of interest.

Acknowledgements

We would like to thank Yuanyuan Chen for the help with language polishing.

Funding

This work was funded by the State Key Program of National Natural Science of China (U1808202), NSFC International (regional) cooperation and exchange program (31961143024), the Key Program of Inner Mongolia (2019ZD006).

Authors' contributions

Zhang JS, Li ZH, Lu JH and Chen ZL discussed the framework of this article. Zhang JS and Li ZH were responsible for literature collection and manuscript writing. Lu JH and Chen ZL reviewed and edited the content of the whole review.

References

[1] Morse SS. Factors in the emergence of infectious diseases. *Emerg Infect Dis* 1995; **1**(1): 7-15.

[2] Li YF, Lu JH. Efficacy and effectiveness of COVID-19 vaccines: Progress and prospect. *One Health Bull* 2021; **1**(1): 17-23.

[3] Centers for Disease Control and Prevention. *International Conference on Emerging Infectious Diseases. 2018.* [Online] Available from: https://www.cdc.gov/iceid/index.html. [Accessed on 3 August 2018].

[4] Callaway E. Delta coronavirus variant: Scientists brace for impact. *Nature* 2021; **595**(7865): 17-18.

[5] Maslow JN. Challenges and solutions in the development of vaccines against emerging and neglected infectious diseases. *Hum Vaccin Immunother* 2019; **15**(10): 2230-2234.

[6] Poland GA, Whitaker JA, Poland CM, Ovsyannikova IG, Kennedy RB. Vaccinology in the third millennium: Scientific and social challenges. *Curr Opin Virol* 2016; **17**: 116-125.

[7] Soleimanpour S, Yaghoubi A. COVID-19 vaccine: Where are we now and where should we go? *Expert Rev Vaccin* 2021; **20**(1): 23-44.

[8] World Health Organization. *WHO New Measles Surveillance Data for 2019.* [Online] Available from: https://www.who.int/immunization/newsroom/measles-data-2019/en/. [Accessed on 6 February 2020].

[9] Maslow JN. Challenges and solutions in the development of vaccines against emerging and neglected infectious diseases. *Hum Vaccin Immunother* 2019; **15**(10): 2230-2234.

[10] Dyal JW, Grant MP, Broadwater K, Bjork A, Waltenburg MA, Gibbins JD, et al. COVID-19 among workers in meat and poultry processing facilities—19 states, April 2020. *MMWR Morb Mortal Wkly Rep* 2020; **69**(18): 557-561.

[11] Alaska Department of Labor and Workforce Development. *Alaska resident hire information. Nonresidents working in Alaska, 2019.* [Online] Available from: https://live.laborstats.alaska.gov/reshire/index.cfm. [Accessed on 12 November 2019].

[12] State of Alaska. *COVID-19 health mandate. 2020.* [Online] Available from: https://content.govdelivery.com/accounts/AKDHSS/bulletins/282d20b. [Accessed on 23 March 2020].

[13] State of Alaska. *Enhanced protective measures for seafood processing workers: health mandate 010–appendix 01. Anchorage, AK: Alaska Department of Health and Social Services; 2020.* [Online] Available from: https://covid19.alaska.gov/wp-content/uploads/2020/05/COVID-MANDATE-10-Appendix-01.pdf. [Accessed on 6 March 2020]

[14] Centers for Disease Control and Prevention. *COVID-19: Importance of COVID-19 vaccination for essential workers. Atlanta, GA: US Department of Health and Human Services, CDC, 2021.* [Online] Available from: https://www.cdc.gov/coronavirus/2019-ncov/vaccines/recommendations/essentialworker.html. [Accessed on 4 April 2021].

[15] World Health Organization. *Hepatitis B.* [Online] Available from: http://www.who.int/mediacentre/factsheets/fs204/en. [Accessed on 16 November 2015]

[16] Jia JD, Zhuang H. A winning war against hepatitis B virus infection in China. *Chin Med J (Engl)* 2007; **120**(24): 2157-2158.

[17] Dai Z, Qi G. *Virus hepatitis in China: Seroepidemiological survey in Chinese population (part one) 1992–1995.* Beijing: Beijing Science and Technology Literature Press; 1996, p. 8-103.

[18] Xia GL, Liu CB, Cao HL, Bi SL, Zhan MY, Su CA, et al. Prevalence of hepatitis B and C virus infections in the general Chinese population: Results from a nationwide cross-sectional seroepidemiologic study of hepatitis A, B, C, D and E virus infections in China, 1992. *Int Hepatol Commun* 1996; **5**: 62-73

[19] Dai ZC, Qi GM. *Seroepidemiological Survey in Chinese population (part one), 1992–1995.* Beijing: Science and Technology Literature Press; p. 60-71.

[20] Bruguera M, Forns X. Current epidemiology of viral hepatitis: Who is affected and who can be protected? *Enferm Infecc Microbiol Clin* 2004; **22**(8): 443-447.

[21] He J, Gu DF, Wu XG, Kristi R, Duan XF, Yao CH, et al. Major causes of death among men and women in China. *N Engl J Med* 2005; **353**(11): 1124-1134.

[22] Perz JF, Armstrong GL, Farrington LA, Hutin YJF, Bell BP. The contributions of hepatitis B virus and hepatitis C virus infections to cirrhosis and primary liver cancer worldwide. *J Hepatol* 2006; **45**(4): 529-538.

[23] Evans AA, Chen G, Ross EA, Shen FM, Lin WY, Thomas LW, et al. Eight-year follow-up of the 90 000-person Haimen City cohort: I. Hepatocellular carcinoma mortality, risk factors, and gender differences. *Cancer Epidemiol Biomark Prev* 2002; **11**(4): 369-376.

[24] Liang XF, Bi SL, Yang WZ, Wang LD, Cui G, Cui FQ, et al. Epidemiological serosurvey of hepatitis B in China--declining HBV prevalence due to hepatitis B vaccination. *Vaccine* 2009; **27**(47): 6550-6557.

[25] Liang XF, Bi SL, Yang WZ, Wang LD, Cui G, Cui FQ, et al. Evaluation of the impact of hepatitis B vaccination among children born during 1992-2005 in China. *J Infect Dis* 2009; **200**(1): 39-47.

[26] Shepard CW, Simard EP, Finelli L, Fiore AE, Bell BP. Hepatitis B virus infection: Epidemiology and vaccination. *Epidemiol Rev* 2006; **28**: 112-125.

[27] Sun Z, Ming L, Zhu X, Lu J. Prevention and control of hepatitis B in China. *J Med Virol* 2002; **67**(3): 447-450.

[28] Ministry of Health. *National EPI review in 2004.* Beijing: Chinese people's health express; 2005, p. 24.

[29] Kane MA, Hadler SC, Lee L, Shapiro CN, Cui F, Wang X, et al. The inception, achievements, and implications of the China GAVI Alliance Project on Hepatitis B Immunization. *Vaccine* 2013; **31**(Suppl 9): J15-J20.

[30] Liang X, Cui F, Hadler S, Wang X, Luo H, Chen Y, et al. Origins, design and implementation of the China GAVI project. *Vaccine* 2013; **31** (Suppl 9): J8-J14.

[31] Centers for Disease Control and Prevention Progress in hepatitis B prevention through universal infant immunization—China, 1997-2006. *MMWR Morb Mortal Wkly Rep* 2007; **56**(18): 441-445.

[32] Wang Z, Chen Y, Pan J. Trends of acute hepatitis B notification rates in eastern China from 2005 to 2013. *PLoS One* 2014; **9**(12): e114645.

[33] Dooling K, McClung N, Chamberland M, Marin M, Wallace M, Bell BP, et al. The Advisory Committee on immunization practices' interim recommendation for allocating initial supplies of COVID-19 vaccine—United States, 2020. *MMWR Morb Mortal Wkly Rep* 2020; **69**(49): 1857-1859.

[34] Beer T. *Large numbers of health care and frontline workers are refusing Covid–19 vaccine, 2021.* [Online] Available from https://www.forbes.com/sites/tommybeer/2021/01/02/large-numbers-of-health-care-and-frontline-workers-are-refusing-covid-19-vaccine/?sh=138be113c962. [Accessed on 28 May 2021]

[35] Inskeep S, Glenn H. *At Houston hospital, Head of COVID–19 Unit sees some staff wary of a vaccine. 2020.* [Online] Available from: https://www.npr.org/2020/12/16/947248103/at-houston-hospital-head-of-covid-19-unit-sees-some-staff-wary-of-a-vaccine. [Accessed on 28 May 2021]

[36] Dror AA, Eisenbach N, Taiber S, Morozov NG, Mizrachi M, Zigron Z, et al. Vaccine hesitancy: The next challenge in the fight against COVID-19. *Eur J Epidemiol* 2020; **35**(8): 775-779.

[37] Lucia VC, Kelekar A, Afonso NM. COVID-19 vaccine hesitancy among medical students. *J Public Health (Oxf)* 2021; **43**(3): 445-449.

[38] Hall VJ, Foulkes S, Saei A, Andrews N, Oguti B, Charlett A, et al. COVID-19 vaccine coverage in health-care workers in England and effectiveness of BNT162b2 mRNA vaccine against infection (SIREN): A prospective, multicentre, cohort study. *Lancet* 2021; **397**(10286): 1725-1735.

[39] Mandavilli A. *At elite medical centers, even workers who don't qualify are vaccinated.2021.* [Online] Available from https://www.nytimes.com/2021/01/10/health/coronavirus-hospitals-vaccinations.html. [Accessed 28 May 28 2021]

[40] Goldberg E. *Some medical students celebrate with Covid vaccine selfies as others wait in line. 2021.* [Online] Available from: https://www.nytimes.com/2021/01/14/health/covid-vaccine-medical-schools.html. [Accessed on 28 May 2021]

[41] La Torre G, Mannocci A, Ursillo P, Bontempi C, Firenze A, Panico MG, et al. Prevalence of influenza vaccination among nurses and ancillary workers in Italy: Systematic review and meta analysis. *Hum Vaccin* 2011; **7**(7): 728-733.

[42] La Torre G, Saulle R, Unim B. Hepatitis B immunization in health care workers: Needs and opportunities. *Hepat Mon* 2011; **11**(8): 664-665.

[43] Fortunato F, Tafuri S, Cozza V, Martinelli D, Prato R. Low vaccination coverage among Italian healthcare workers in 2013. *Hum Vaccin Immunother* 2015; **11**(1): 133-139.

[44] Maltezou HC, Poland GA. Vaccination policies for healthcare workers in Europe. *Vaccine* 2014; **32**(38): 4876-4880.

[45] Prato R, Tafuri S, Fortunato F, Martinelli D. Vaccination in healthcare workers: An Italian perspective. *Expert Rev Vaccin* 2010; **9**(3): 277-283.

[46] Loulergue P, Moulin F, Vidal-Trecan G, Absi Z, Demontpion C, Menager C, et al. Knowledge, attitudes and vaccination coverage of healthcare workers regarding occupational vaccinations. *Vaccine* 2009; **27**(31): 4240-4243.

[47] Dinelli MI, Moreira TD, Paulino ER, da Rocha MC, Graciani FB, de Moraes-Pinto MI. Immune status and risk perception of acquisition of vaccine preventable diseases among health care workers. *Am J Infect Control* 2009; **37**(10): 858-860.

[48] Haviari S, Bénet T, Saadatian-Elahi M, André P, Loulergue P, Vanhems P. Vaccination of healthcare workers: A review. *HumVaccin Immunother* 2015; **11**(11): 2522-2537.

[49] Albano L, Matuozzo A, Marinelli P, Giuseppe DG. Knowledge, attitudes and behaviour of hospital health-care workers regarding influenza A/H1N1: A cross sectional survey. *BMC Infect Dis* 2014; **14**: 208.

[50] Amendola A, Bianchi S, Lai A, Canuti M, Piralla A, Baggieri M, et al. Measles re-emergence in Northern Italy: Pathways of measles virus genotype D8, 2013–2014. *Infect Genet Evol* 2017; **48**: 120-126.

[51] Boccalini S, Bonanni P, Bechini A. Preparing to introduce the varicella vaccine into the Italian immunisation programme: Varicella-related hospitalisations in Tuscany, 2004-2012. *Euro Surveill* 2016; **21**(24): 10.

[52] Giambi C, Filia A, Rota MC, Del Manso M, Declich S, Nacca G, et al. Congenital rubella still a public health problem in Italy: Analysis of national surveillance data from 2005 to 2013. *Euro Surveill* 2015; **20**(16): 21103.

[53] Gabutti G, Guido M, Rota MC, De Donno A, Ciofi DAML, Crovari P. The epidemiology of mumps in Italy. *Vaccine* 2008; **26**(23): 2906-2911.

[54] Bechini A, Tiscione E, Boccalini S, Levi M, Bonanni P. Acellular pertussis vaccine use in risk groups (adolescents, pregnant women, newborns and healthcare workers): A review of evidences and recommendations. *Vaccine* 2012; **30**(35): 5179-5190.

[55] Maltezou HC, Poland GA. Immunization of health-care providers: Necessity and public health policies. *Healthcare* 2016; **4**(3): 47.

[56] Yue N, Wang Q, Zheng MY, Wang DL, Duan CX, Yu XG, et al. Prevalence of hepatitis E virus infection among people and swine in mainland China: A systematic review and meta-analysis. *Zoonoses Public Health* 2019; **66**(3): 265-275.

[57] Liu W, Min L, Zhang QF. Investigation on awareness of hepatitis E vaccine and willingness to inoculate among occupational populations related to viral hepatitis. *Chin J Biologic* 2014; **27**(04): 582-584.

[58] Wang QY, Liu M, Liu XJ. Investigation on knowledge,attitude,and practice of viral hepatitis among professionals related to swine raising in Beijing. *Capital J Public Health* 2011; **5**(05): 207-209.

[59] Gautret P, Botelho-Nevers E, Brouqui P, Parola P. The spread of vaccine-preventable diseases by international travellers: A public-health concern. *Clin Microbiol Infect* 2012; **18**(Suppl 5): 77-84.

[60] Barasheed O, Rashid H, Heron L, Ridda I, Haworth E, Nguyen-Van-Tam J, et al. Influenza vaccination among australian hajj pilgrims: Uptake, attitudes, and barriers. *J Travel Med* 2014; **21**(16): 384-390.

[61] Goodman AL, Masuet-Aumatell C, Halbert J, Zuckerman JN. Awareness of meningococcal disease among travelers from the United Kingdom to the meningitis belt in Africa. *Am J Trop Med Hyg* 2014; **91**(2): 281-286.

[62] Heywood AE, Nothdurft H, Tessier D, Moodley M, Rombo L, Marano C, et al. Pre-travel advice, attitudes and hepatitis A and B vaccination rates among travellers from seven countries. *J Travel Med* 2016; **24**(1): taw069.

[63] Tashani M, Alfelali M, Azeem MI, Fatema FN, Barasheed O, Alqahtani AS, et al. Barriers of vaccinations against serious bacterial infections among Australian Hajj pilgrims. *Postgrad Med* 2016; **128**(6): 541-547.

[64] Duffy MR, Reed C, Edelson PJ, Blumensaadt S, Crocker K, Griggs A, et al. A survey of US travelers to Asia to assess compliance with recommendations for the use of Japanese encephalitis vaccine. *J Travel Med* 2013; **20**(3): 165-170.

[65] Alqahtani AS, Wiley KE, Tashani M, Willaby HW, Heywood AE, BinDhim NF, et al. Exploring barriers to and facilitators of preventive measures against infectious diseases among Australian Hajj pilgrims: Cross-sectional studies before and after Hajj. *Int J Infect Dis* 2016; **47**: 53-59.

[66] Savage J, Muller F, Ormerod AD. Awareness and uptake of recommended vaccines among immunosuppressed patients. *J R Coll Phys Edinb* 2011; **41**(3): 202-205.

[67] Gagneux-Brunon A, Fresard A, Lucht F, Botelho-Nevers E. Vaccine coverage in PLWH: Disparities and potential impact of vaccine hesitancy. *Hum Vaccin Immunother* 2019; **15**(2): 305-306.

[68] Loubet P, Verger P, Abitbol V, Peyrin-Biroulet L, Launay O. Pneumococcal and influenza vaccine uptake in adults with inflammatory bowel disease in france: Results from a web-based study. *Dig Liver Dis* 2018; **50**(6): 563–567.

[69] Hobson-West P. 'Trusting blindly can be the biggest risk of all': Organised resistance to childhood vaccination in the UK. *Sociol Health Illn* 2007; **29**(2): 198-215.

[70] International Committee on Taxonomy of Viruses (ICTV). *Virus Taxonomy: The ICTV Report on Virus Classification and Taxon Nomenclature 2011.* [Online] Available from: Virus Taxonomy: The ICTV Report on Virus Classification and Taxon Nomenclature | ICTV. [Accessed on 21 September 2011]

[71] Wan P, Chen H. Epidemiological characteristics of influenza among human beings since the 1900's. *Chem Life* 2011; **31**: 605-611.

[72] Zeng XX, Li KS. The pandemic history of influenza: Review and revelation of the influenza pandemic in last century. Med Soc 2010; **23**: 4-6.

[73] Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. *Philos Trans R Soc Lond B Biol Sci* 2001; **356**(1411): 983.

[74] Centers for Disease and Control and Prevention. *Bioterrorism A—gents/Disease.* [Online] Available from: https://emergency.cdc.gov/agent/agentlist-category.asp. [Accessed on 4 April 2018].

[75] Mehta NS, Mytton OT, Mullins EWS, Fowler TA, Falconer CL, Murphy OB, et al. SARS-CoV-2 (COVID-19): What do we know about children? A Systematic Review. *Clin Infect Dis* 2020; **71**(9): 2469-2479.

[76] Roy J, Jain R, Golamari R, Vunnam R, Sahu N. COVID-19 in the geriatric population. *Int J Geriatr Psychiatry* 2020; **35**(12): 1437-1441.

[77] Joshi SR, Tiwaskar MH, Shah SN. COVID 19: Diabetes and obesity API-ICP recommendations. *J Assoc Physicians India* 2020; **68**(5): 42-44.

[78] Olloquequi J. COVID-19 Susceptibility in chronic obstructive pulmonary disease. *Eur J Clin Invest* 2020; **50**(10): e13382.

[79] World Health Organization. *Hepatitis E.* [Online] Available from: https://www.who.int/en/news-room/fact-sheets/detail/hepatitis-e. [Accessed on 7 March 2021]

[80] Su CP, de Perio MA, Cummings KJ, McCague AB, Luckhaupt SE. Case investigations of infectious diseases occurring in workplaces, United States, 2006-2015. *Sweeney MH Emerg Infect Dis* 2019; **25**(3): 397-405.

[81] Haagsma JA, Tariq L, Heederik DJ, Havelaar AH. Infectious disease risks associated with occupational exposure: A systematic review of the literature. *Occup Environ Med* 2012; **69**(2): 140-146.

[82] Gao F, Chen JS, Zhao GP, Xu JG, Lu JH. The 697th Xiangshan Science Conference consensus report on One Health and human health. *One Health Bull* 2021; **1**(1): 3-9.

Publisher' s note

The Publisher of the *Journal* remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.