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Who should be Prioritized for COVID-19 Vaccination in China? A Descriptive Study

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Abstract

All countries are facing decisions about which groups to prioritise for COVID-19 vaccination after the first vaccine product has been licensed, at which time supply shortages are inevitable. Here we define the key target populations and their size in China for a phased introduction of COVID-19 vaccination with evolving goals, accounting for the risk of illness and transmission. Essential workers (47.2 million) like healthcare workers could be prioritized for vaccination to maintain essential services. Subsequently, older adults, individuals with underlying health conditions and pregnant women (616.0 million) could be targeted to reduce severe COVID-19 outcomes. Then it could be further extended to target adults without underlying health conditions and children (738.7 million) to reduce symptomatic infections and/or to stop virus transmission. The proposed framework could assist Chinese policy-makers in the design of a vaccination program, and could be generalized to inform other national and regional COVID-19 vaccination strategies.

Key words: Novel coronavirus diseases 2019; vaccination; target population; China

This study does not necessarily represent the views of the US government or the National Institutes of Health.

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Running head: Priority populations for COVID-19 vaccination in China

Introduction

Coronavirus disease 2019 (COVID-19) pandemic is causing unprecedented impact on global health and the economy. In the absence of safe and highly effective vaccines and treatment options, non-pharmaceutical interventions are used to decrease transmission and reduce the burden of COVID-19 but most of these interventions have large economic costs.[1] Effective vaccines against COVID-19 are urgently needed to reduce the significant burden of COVID-19 morbidity and mortality. Globally, there are over 300 vaccine candidates at various stages of development in the research pipeline. Of these, over 30 candidates have entered clinical trials.[2,3]

On June 26, 2020, the World Health Organization (WHO) unveiled a plan to deliver 2 billion doses of COVID-19 vaccines, of which 50% will go to low-and-middle income countries, by the end of 2021.[4] Currently, the projected global production capacity is inadequate to provide COVID-19 vaccines for every human being on the planet, particularly immediately after the first vaccine has been licensed. It is possible that countries and entire regions will have no access to vaccines. For example, COVID-19 cases are rapidly increasing in most African countries. [5] However, none of the COVID-19 vaccine candidates is being developed by an African manufacturer. Even if a vaccine were available, many low-income countries would have to rely on vaccines manufactured abroad. Hence national and multinational vaccine producers will need to allocate a proportion of their production to countries that do not have the financial ability to pre-order vaccine doses that are still to be licensed. Setting priorities for target populations to be vaccinated and optimizing resources within and between countries entails difficult choices. Nonetheless, this is critical for a successful global pandemic vaccination program, and this needs to be addressed urgently.

China was the first country to face the COVID-19 pandemic, although only Wuhan, in Hubei Province, was hit by a major wave of infections.[6] Nearly the entire population of mainland China (~1.4 billion people) is still susceptible to COVID-19. Recent surges of COVID-19 cases occurred separately in Beijing, Dalian, and Urumchi after one or more months without any report of locally-acquired infections[7]. There is a risk of a new major wave of COVID-19, especially after the economy and society have re-opened both domestically and abroad.

China has invested substantial resources in vaccines and is one of the main actors in the race to develop a vaccine to help control the COVID-19 pandemic, with resources provided by government, manufacturers and non-governmental organizations.[8] Over ten vaccine candidates are being developed in mainland China; three of them (developed by Sinovac Instituto Butantan, Wuhan Institute of Biological Products/Sinopharm, and Beijing Institute of Biological Products/Sinopharm) are in phase III trials as of August 13, 2020.[2] New COVID-19 vaccine production facilities recently completed or currently under construction are expected to have the capacity to produce 1 billion doses annually.[9-11] However, the output is far behind the quantity needed to vaccinate a population of nearly 1.4 billion people in mainland China alone (given a two-dose schedule for all vaccine candidates). Hence, there is a need to establish priority target populations for a COVID-19 vaccination program. This study aims to define the key target populations, their size, and priority for a phased introduction of COVID-19 vaccination with evolving goals, accounting for risk of severe illness and transmission. This approach is generalizable to inform national and regional strategies for the use of COVID-19 vaccines, especially in low-and-middle income countries.

Results

For a phased COVID-19 vaccination program, the most important objective (*primary goal*) of the vaccination program is to maintain essential services (e.g., healthcare and national security) in the early phase.[12,13] The second objective (*secondary goal*) is to reduce the number of individuals with severe outcomes, including hospitalizations, critical care admissions, and deaths.[12,13] In later stages, the objective of the vaccination program can be further extended to reduce symptomatic infections and/or to stop virus transmission (*tertiary goal*). Subsequently, these population groups were categorized into six vaccination tiers in order of decreasing priority. Figure 1 illustrates the priority population groups relevant for each goal and the corresponding population size estimated without excluding duplicates between groups.

Essential workers

It is important to stress that the vaccine may be in extremely short supply when first available. To meet the primary goal of vaccination, thus it could be necessary to consider healthcare workers as the top priority (Tier 1 of the vaccination strategy) based on utilitarian (i.e. maximizing health and economic benefit) and egalitarian (i.e. protecting the worst off) principles. Law enforcement and security workers, personnel in nursing home and social welfare institutes, community workers, workers in energy, food and transportation sectors are included in Tier 2 based on utilitarian principles (Figure 1). We estimated that in mainland China there are 10.7 million healthcare workers, 4.4 million people working in law enforcement agencies and security personnel, 0.4 million personnel in nursing home and social welfare institutes, 4.5 million community workers, and 27.3 million workers in the energy, food, and transportation sectors.

High-risk individuals

As of August 12, 2020, a total of 76 systematic reviews reported the pooled risk of severe outcome of COVID-19, including hospitalizations, critical care admissions, and deaths. Among them, 55 (72%) were peer-reviewed and published. 71% (54/76) of systematic reviews evaluated the quality of included original articles, and reported that the majority of included studies were of moderate-to-high quality. (Supplementary Materials Table S1, and Figure S1-S2)

The published systematic reviews showed that increased risk of severe outcomes from SARS-CoV-2 infection were observed in individuals with chronic respiratory disease including but not limited to chronic obstructive pulmonary diseases (38 of 43 papers report significant association, OR/RR: mean 1.53-17.80), heart disease (3 of 3 papers, 2.03-4.09), cardio-cerebrovascular disease (22 of 25 papers, 1.44-36.88), hypertension (26 of 26 papers, 1.66-5.34), diabetes (28 of 30 papers, 1.39-4.64), chronic renal diseases (8 of 9 papers, 1.84-9.41), chronic liver disease (3 of 9 papers, 1.48-2.69), cancer (14 of 17 papers, 1.56-4.86), and obesity (5 of 7 papers, 1.21-3.68)[14-66] (Supplementary Materials Figure S1). Only one systematic review evaluated the disease severity of COVID-19 during pregnancy, and found that 21% were severe/critical cases.[67] COVID-19 may cause fetal distress, miscarriage, respiratory distress and preterm delivery, although evidence for these associations is still inconclusive.[68] Moreover, pregnant women have high frequency of antenatal care visits and thus have a possibly higher exposure to SARS-CoV-2. Although no systematic review found a significantly higher risk of severe outcomes for those with immunodeficiency/immunosuppression, chronic neurological disorders, and sickle cell disorders, we included these categories in our analysis as recommended by the US and UK.[27,69-71]

Age is one of the most important risk factors for severe/fatal COVID-19. Our systematic reviews showed that individuals age ≥ 60 years had about 4-fold higher risk of severe/fatal COVID-19 than younger people (Supplementary Materials, Figure S1-S2). Wu et al. found that the case-fatality risk for those aged ≥80 years was 1.7-3.6 times that among those aged 70-79, and 60-69 years.[72] Age and underlying conditions combine to increase the risk.[73] Accordingly, adults ≥ 60 years of age with underlying conditions, and adults ≥ 80 years of age without underlying conditions, who are at the highest risk of severe/fatal COVID-19, were considered in Tier 3, based on egalitarian principles. Compared to these persons, the risk of severe/fatal COVID-19 among older adults aged 60-79 years without underlying conditions and individuals <60 years of age with underlying conditions was lower. These individuals aged < 60 years with pre-existing medical conditions and pregnant women were included in Tier 4 based on egalitarian principles (Figure 1).

We estimated that 363.3 million individuals aged <60 years and 158.1 million individuals aged ≥ 60 years had at least one high-risk medical condition in mainland China. The number of pregnant women was thus estimated at 26.3 million in mainland China (Figure 1).

Individuals at high risks of symptomatic COVID-19 infections

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Population-based studies demonstrated that the incidence of COVID-19 cases in those aged 20-59 years was similar to that among older adults.[6,74] (Supplementary Materials Table S2-S3). Our meta-analysis showed the cumulative incidence was 139-161 per 100,000 persons among those aged 20-59 years, which was comparable to incidence in those aged ≥ 60years (195 per 100,000 persons) (Figure 2). These working age adults had a higher risk of acquiring COVID-19 symptomatic infection possibly because of their large number of contacts at work and in the community.[75] Additionally, they contribute to maintenance of societal functions and economic well-being; and they generally provide care for children. Given these considerations, individuals aged 20-59 years without underlying conditions (n=551.3 million) were included in Tier 5 based on both utilitarian and egalitarian principles (Figure 1).

Population-based sero-epidemiological studies also reported lower seroprevalence in children than in adults.[76,77] Whether this reflects lower susceptibility of children to infection in general, or similar infection rates, but much higher proportions with asymptomatic disease, or rather the effect of school closures, the implemented strict social distancing measures, or a self-protective behavior of the population remains unclear. Modeling studies found conflicting results about the effect of interventions targeted at children on SARS-CoV-2 transmission at the community level,[78,79] suggesting that there is still uncertainty surrounding fundamental epidemiological parameters of COVID-19 related to children (e.g., their infectiousness,[80,81] susceptibility to infection,[82,83] and probability of developing symptoms).[84] To ensure the continuity of educational activities, and reduce transmission, school-age children (n=190.2 million) are recommended for vaccination in Tier 6 based on both utilitarian and egalitarian principles (Figure 1).

The incidence of COVID-19 was lower in younger children. However, the severity among young children has not been fully addressed. Verdoni et al., reported an outbreak of a novel severe Kawasaki-like disease in children related to COVID-19 in Italy, which raised concerns about the impact of the pandemic on younger children.[85] Considering such possible post-infectious inflammatory syndrome as Kawasaki-like disease, younger children aged ≤5 years (n=98.7

million), which are priority groups for influenza vaccination, are recommended in Tier 6 as well, based on egalitarian principles of prioritizing the most vulnerable individuals (Figure 1).

Estimated size of target population of the phased universal vaccination program

To maintain essential societal functions, the target population of vaccination was estimated at 47.2 million (Tiers 1 and 2, Figure 1 and Figure 3). An additional 616.0 million persons were included in the target population if the goal of vaccination was extended to reduce the number of severe COVID-19 cases (Tiers 3 and 4, Figure 1 and Figure 3). Along with the increase of vaccine supply, the remaining 738.7 million persons could be further targeted for vaccination to reduce the total number of COVID-19 symptomatic cases and potentially halt transmission (Tiers 5 and 6, Figure 1 and Figure 3). In terms of vaccination tiers (from Tier 1 to Tier 6), a total of 10.7, 36.5, 163.3, 452.7, 502.5 and 236.2 million persons were included in the target population (Figure 4).

Given 3 million doses administered per day, and a two-dose vaccination schedule, it will likely take about 19 months to vaccinate 60% of the overall population. However, only three weeks would be required to vaccinate individuals working in critical infrastructure sectors (Tier 1 and 2), two months for Tier 3, six months for Tier 4, about seven months for Tier 5, and three months for Tier 6 (Figure 5). With an expected one billion doses produced per year,[9-11], and given a fixed 60% uptake rate among Tiers, the estimated vaccine supply could cover individuals in Tier 1-3 and one fifth of individuals in Tier 4 given a two-dose vaccination schedule.

The sensitivity analyses show it will take two years to vaccinate 80% of individuals given 3 million doses administered each day; 3.5 years to vaccinate 60% of individuals given 1.3 million doses administered each day; 4.7 years to vaccinate 80% of individuals given 1.3 million doses administered each day (Supplementary Materials, Figure S4-S6). It will take about one year and 10 months to vaccinate 80% and 60% of individuals respectively, if the capacity of COVID-19 vaccination delivery was scaled up to 6 million doses administered each day (Supplementary

Materials, Figure S7-S8).

Discussion

In the absence of specific antiviral treatment for COVID-19, vaccination likely represents the most promising way to control the COVID-19 pandemic. However, even if a COVID-19 vaccine becomes available, initial supplies will inevitably be limited. Supply issues could persist in the long-term, due to huge global demand and limited production capacity. Almost everyone can potentially benefit from vaccination because of residual high susceptibility to SARS-CoV-2 infection. Considering different goals of a future vaccination program, changes in vaccine supplies, various levels of responsibility of population groups to the COVID-19 pandemic responses and essential services, as well as the risk of severe outcome and illness, we recommend a phased universal COVID-19 vaccination program for mainland China. Workers in critical sectors, including healthcare workers, law enforcement and security personnel, personnel in nursing home and social welfare institutes, as well as sectors of energy, water, food, and transportation (47.2 million) are the main candidates to receive high priority for vaccination, in order to maintain essential societal functions. Subsequently, we propose to extend the vaccination program to older adults, pregnant women, and those with underlying medical conditions (616.0 million), in order to reduce severe outcomes of COVID-19. Finally, working-age adults, school-age children and younger children (738.7 million) could be vaccinated in order to reduce symptomatic COVID-19 infections, and/or to stop SARS-CoV-2 transmission.

Target population groups are further grouped into vaccination tiers from 1 to 6, with Tier 1 having the highest priority. Even though individuals within a tier have equal priority for vaccination, it may be necessary to sub-prioritize vaccination of groups within a tier in case of extremely short initial vaccine supplies. For instance, meat and poultry processing facility workers, who have been particularly affected by COVID-19 and often linked to workplace transmission, could be vaccinated before other personnel in the food supply chain within Tier 2.[72,86] Although other factors like smoking, being male, and being an ethnic minority were found to be risk factors of severe outcome and deaths from COVID-19 in previous studies, [87-89] they were not accounted for when determining priority population here due to consideration of equity and feasibility of vaccination.

The majority of the current COVID-19 vaccine candidates are being trialed as two dose schedules.[2] A total of 57 million, 739 million and 886 million doses are separately needed to cover 60% of individuals in critical infrastructure sectors, persons at high risk of severe outcomes of COVID-19, and persons at high risk of acquiring symptomatic illness/infections. Between 2007 and 2015, the volume supplied of all vaccines (n=55) licensed in mainland China varied from 666 million doses to 1.19 billion doses per year.[90] Several manufacturers state that a total of 1 billion doses of COVID-19 vaccine could be produced annually.[9-11] This implies that the potential production capacity may be far behind the demand in mainland China given a two-dose schedule. This dilemma is likely not unique to China and other countries across the world, particularly in low-and-middle income regions, will face a similar challenge.

Even at the maximum rate at which H1N1pdm vaccines were delivered in 2009 (3 million doses administered each day), vaccinating 60% of the general population groups will take 1.5 years, without considering limits in production capacity. Such a large-scale vaccination program like COVID-19 could also represent a major challenge for current the National Immunization Program in China, which is currently focused on childhood vaccination rather than on adult vaccination. The limited production capacity will likely further delay COVID-19 vaccination programs.

Our study has a number of limitations. First, we have qualitatively discussed the segments of the population to be prioritized in a COVID-19 vaccination program as well as the rationale behind prioritization choices. However, we could not quantitatively examine whether prioritizing older adults to reduce severe outcomes is a better choice than prioritizing working-aged adults or school-age children to reduce illness/transmission. Mathematical modelling is urgently needed to assess both the health and economic impacts of potential vaccination strategies, and the potential to reduce for herd immunity benefits. Second, we did not consider eligibility for vaccination due to lack of efficacy and/or safety concerns that may affect specific groups such as older adults, people with pre-existing medical conditions, pregnant women and very young children, since no vaccine has been licensed yet. Third, we did not consider real-time reactive outbreak immunization strategies because it is impossible to estimate the corresponding target population size. However, we strongly recommend use of COVID-19 vaccination during local outbreaks coupled with other non-pharmaceutical interventions in order to prevent subsequent waves of disease. Moreover, we did not discuss prioritization based on geography; the risk of COVID-19 exposure may be low in regions that have seen widespread COVID-19 activity by the time the vaccine is available and have a high level of population immunity. This may not be particularly relevant for China where the epidemic has been well controlled, but it may affect vaccine prioritization in other regions.

When a vaccine becomes available, our recommendations need to be reassessed to consider the eligibility of population subgroups based on the licensure label. They also need to be further reassessed periodically to account for changes in vaccine supply, demand and local epidemiology. Although we propose a general framework to define vaccination priorities, the proposed vaccination program needs to be tailored locally, accounting for country-specific contexts such the objectives of the pandemic responses, the local level of transmission, the make-up of first responders and essential workers as well as the capacity of immunization services.

Because of the high burden and limited capacity for vaccine production, we have highlighted that more attention should be paid to low-and-middle income countries. The WHO SAGE Working Group on COVID-19 Vaccines has been established in June, 2020 and includes an international team of experts.[91] Their objectives include, but are not limited to, providing recommendations for early allocation of vaccines when vaccine supply is still constrained, and guidance on fair and equitable global access to vaccination. There is an urgent need for the WHO SAGE Working

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Group to promote global cooperation on vaccine research and development, ensure vaccine production and supply, and speed up the development of guidelines for allocating and targeting COVID-19 pandemic vaccines. Our recommendations for mainland China could be used as a template for such guidelines.

Conclusions

Vaccine deployment is likely to become vitally important for the global response to the COVID-19 pandemic. Here we provide a general framework to define priority groups for a phased introduction of a universal COVID-19 vaccination program. We applied this framework to mainland China and further estimated the corresponding target population sizes. The proposed vaccination program could assist Chinese policy-makers in the roll-out of a large-scale immunization program and be used as a reference for other countries, especially in low-and-middle income regions. We recommend that the WHO SAGE Working Group on COVID-19 Vaccines takes the lead on making recommendations on priority target population for national/regional COVID-19 vaccination program, to ensure that all individuals, regardless of where they live, can benefit from a COVID-19 vaccine.

Methods

Goals of the COVID-19 vaccination program

The overarching goal of a vaccination program in the midst of such a pandemic, which can be characterized as having both very high transmissibility and clinical severity[92], is to vaccinate all persons willing to be vaccinated. However, due to limited supplies, prioritization is warranted. The specific goal of COVID-19 vaccination in China could be determined in a phased approach, taking account 1) the interim framework for COVID-19 vaccine allocation and available guidance (e.g. from the US) on allocating vaccines during an influenza pandemic,[12,13] 2) the objectives of and experience gained from the 2009 H1N1pandemic vaccination program in China,[93] 3) specific high-risk groups for severe COVID-19 outcomes, and 4) lessons learned from the response to the

COVID-19 outbreak in Wuhan such as the role of critical workers in sustaining essential societal functions[1]. These goals should be adapted along with the evolving dynamic of the epidemic and an increase of vaccine supplies.

Priority population groups for a COVID-19 vaccination program

In line with the aforementioned goals of a COVID-19 vaccination program, we define population groups to be prioritized by occupation, age, and underlying conditions (Figure 1). Prioritization is based on utilitarian (i.e. maximizing health and economic benefit) and egalitarian (i.e. protecting the worst off) principles. Priority groups include: 1) essential workers, including but not limited to healthcare workers (utilitarian principles); 2) high-risk individuals such as those at the highest risk of severe/fatal outcomes (egalitarian principles); 3) individuals who play a key role in transmission (both utilitarian and egalitarian principles).[94] Within the populations of interest for the primary and tertiary vaccination goals, the target population groups that met ≥2 of the aforementioned principles were assigned to a higher tier. For the secondary goal, the target population at higher risk of severe/fatal COVID-19 outcome was assigned to a higher tier. Across priority population groups, vaccines can be allocated and administered according to tier, which means that all groups within a tier have equal priority for vaccination.

Essential workers

Individuals who are critical for preserving essential societal functions for public health and safety as well as the well-being of the community during a pandemic include: 1) first responders who may have close contact with potential COVID-19 patients in professional settings, including healthcare, public health, and community workers (these include staff in community service agencies, who maintain supply of daily essential needs for people under lockdown, and take routine prevention measures such as fever screening and environmental disinfection); 2) individuals who are essential for maintaining national security, namely individuals working in law enforcement agencies and security personnel (police and military); 3) workers maintaining production and supply of daily essentials, including energy, water, food, and transportation. The detailed definitions and their roles were presented in Supplementary Materials "More detailed methods". We recommend these individuals to be an appropriate first-level priority target group for vaccination. We obtained the population size stratified by occupation from publicly available data, including the China Statistical Yearbook 2019, White Paper on China's National Defense, and published literature.[95,96]

High-risk individuals

To meet the secondary goal of the vaccination program, individuals who are at increased risk for severe outcome of COVID-19 could be considered a priority target population for vaccination. We conducted a narrative literature review to identify the risk factors of severe illness associated with COVID-19. Clark and colleagues extracted the prevalence of underlying health conditions from the Global Burden of Diseases, Risk Factors, and Injuries Study (GBD), and estimated the number of people with at least one of these conditions in 2020 for 188 countries.[97] Using Clark's method, we updated the probability of having at least one of these conditions for China to additionally include the prevalence of BMI≥30, which were identified as risk factors by our review. Then we estimated the age-specific population size of individuals with any of these conditions by multiplying the estimated probability by the UN mid-year population estimates for 2020 for China[98]. The population size of individuals without these conditions was calculated subtracting those with health conditions from the total population. We estimated the number of women who are pregnant in one year as the sum of all live births, still births, fetal deaths, and abortions in that year. (Details in Supplementary Materials "More detailed methods")

Individuals at high risks of symptomatic COVID-19 infections

A second narrative literature review was conducted to assess the risk of symptomatic COVID-19 infection (details in Supplementary Materials "More detailed methods"). Based on the identified risk factors for symptomatic COVID-19 infections, we defined the target populations for vaccination that would help meet the tertiary goal of reducing illness. The populations size was obtained from UN mid-year population estimates for 2020 for China[98], and Ministry of Education of China[99].

Estimating size of target population of the phased universal vaccination program

First, we estimated the corresponding population size separately for each target population as mentioned above. When a person is included in more than one group, she/he is intended to be vaccinated in the highest tier group in which she/he is included. Accordingly, we then excluded people in more than one risk group to estimate the total population size stratified by goals of vaccination in different phases of the pandemic, and by vaccination tiers.

Further, we estimated the days needed to vaccinate 60% of the targeted population in the sequence of Tiers given a two-dose vaccination schedule, without accounting for the production capacity (see schematic diagram in Supplementary Materials Figure S3). During the 2009 influenza pandemic, an average of 1.3 million daily doses of H1N1pdm vaccines were administered in China , reaching 3 million daily doses at the peak delivery date[100]. In the baseline analysis, the maximum delivery capacity of the H1N1pdm vaccination service was used. Sensitivity analyses on the daily doses administered (1.3 million) and the uptake rates (80%) were conducted. COVID-19 is more of a threat than H1N1pdm2009, and both the willingness to be vaccinated against COVID-19 as well as delivery capacity is likely to be greater[101,102], so we further assumed that the capacity of COVID-19 vaccination service could be scaled up to 6 million doses administered per day.

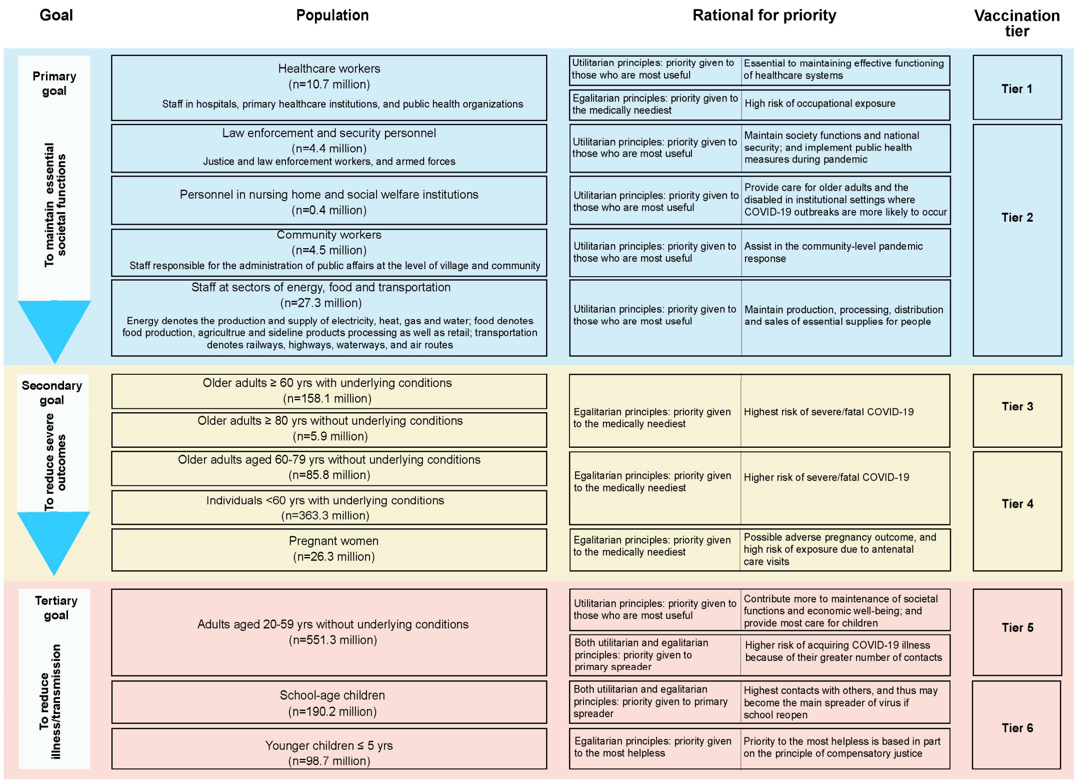

Figure 1. Prioritized segments of the population for a COVID-19 vaccination program as well as estimated population size.

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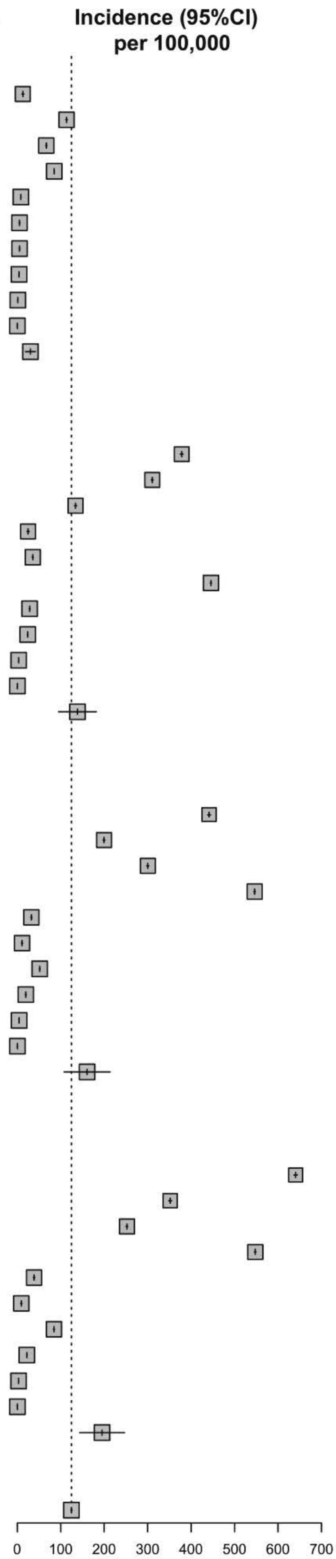
Study	Cases	Total	Weight	Incidence (95%CI) per 100,000
Individuals aged <20 years				
Cruz CJP et al.	148	1,165,354	2.4%	12.7 [10.7; 14.9]
Robert Koch Institute	17,914	15,811,520	2.5%	113.3 [111.6; 115.0]
National Health Service	10,471	15,697,802	2.5%	66.7 [65.4; 68.0]
Stokes EK et al.	69,703	82,003,529	2.6%	85.0 [84.4; 85.6]
BULUT C et al.	741	8,923,702	2.6%	8.3 [7.7; 8.9]
COVID-19 NIRST	326	6,439,454	2.6%	5.1 [4.5; 5.6]
Jung C Y et al.	481	9,330,678	2.6%	5.2 [4.7; 5.6]
Pan A et al.	536	13,400,000	2.6%	4.0 [3.7; 4.4]
Gujski M et al.	87	7,250,000	2.6%	1.2 [1.0; 1.5]
Mazumder A et al.	109	487,064,000	2.6%	0.0 [0.0; 0.0]
Overall		647,086,039	25.6%	30.1 [18.8; 41.5]
Heterogeneity: $Tau^2 = < 0.1$; $Chi^2 = 100410.4$, df = 9 (P = 0); $I^2 = 100\%$				
Individuals aged 20-39 years				
National Health Service	65,513	17,316,598	2.3%	378.3 [375.4; 381.2]
Robert Koch Institute	62,896	20,249,381	2.4%	310.6 [308.2; 313.0]
BULUT C et al.	13,390	9,988,580	2.4%	134.1 [131.8; 136.3]
Cruz CJP et al.	466	1,879,032	2.4%	24.8 [22.6; 27.2]
COVID-19 NIRST	2,529	7,093,798	2.5%	35.7 [34.3; 37.1]
Stokes EK et al.	397,318	89,144,716	2.5%	445.7 [444.3; 447.1]
Jung C Y et al.	3,947	13,878,058	2.6%	28.4 [27.6; 29.3]
Pan A et al.	5,960	24,833,333	2.6%	24.0 [23.4; 24.6]
Gujski M et al.	349	10,906,250	2.6%	3.2 [2.9; 3.6]
Mazumder A et al.	502	455,538,000	2.6%	0.1 [0.1; 0.1]
Overall		650,827,746	24.9%	138.5 [94.8; 182.1]
Heterogeneity: $Tau^2 = < 0.1$; $Chi^2 = 554090.1$, df = 9 (P = 0); $I^2 = 100\%$				
Individuals aged 40-59 years				
National Health Service	77,866	17,641,941	2.2%	441.4 [438.3; 444.5]
BULUT C et al.	29,998	15,023,256	2.4%	199.7 [197.4; 201.9]
Robert Koch Institute	71,265	23,731,744	2.4%	300.3 [298.1; 302.5]
Stokes EK et al.	454,913	83,286,891	2.5%	546.2 [544.6; 547.8]
COVID-19 NIRST	2,076	6,413,795	2.5%	32.4 [31.0; 33.8]
Cruz CJP et al.	250	2,293,578	2.5%	10.9 [9.6; 12.3]
Pan A et al.	12,269	23,777,132	2.6%	51.6 [50.7; 52.5]
Jung C Y et al.	3,206	16,433,791	2.6%	19.5 [18.8; 20.2]
Gujski M et al.	435	10,357,143	2.6%	4.2 [3.8; 4.6]
Mazumder A et al.	360	297,792,000	2.6%	0.1 [0.1; 0.1]
Overall		496,751,271	25.0%	160.6 [107.9; 213.4]
Heterogeneity: $Tau^2 = < 0.1$; $Chi^2 = 654761.4$, df = 9 (P = 0); $I^2 = 100\%$				
Individuals aged >60 years				
National Health Service	106,845	16,677,863	2.1%	640.6 [636.8; 644.5]
BULUT C et al.	44,061	12,523,680	2.2%	351.8 [348.5; 355.1]
Robert Koch Institute	60,519	23,991,300	2.4%	252.3 [250.3; 254.3]
Stokes EK et al.	398,554	72,768,669	2.5%	547.7 [546.0; 549.4]
COVID-19 NIRST	2,144	5,552,834	2.5%	38.6 [37.0; 40.3]
Cruz CJP et al.	153	1,663,043	2.5%	9.2 [7.8; 10.8]
Pan A et al.	13,818	16,372,038	2.5%	84.4 [83.0; 85.8]
Jung C Y et al.	2,603	11,864,454	2.6%	21.9 [21.1; 22.8]
Gujski M et al.	288	9,600,000	2.6%	3.0 [2.7; 3.4]
Mazumder A et al.	192	139,610,000	2.6%	0.1 [0.1; 0.2]
Overall		310,623,881	24.5%	194.9 [143.2; 246.7]
Heterogeneity: $Tau^2 = < 0.1$; $Chi^2 = 631432.4$, df = 9 (P = 0); $I^2 = 100\%$				
Overall		2,105,288,937	100.0%	124.6 [123.3; 125.8]
Heterogeneity: $Tau^2 < 0.1$; $Chi^2 = 1{,}942{,}354.3$, df = 39 (P = 0); $I^2 = 100.0\%$				



401

402 **Figure 2.** Pooled incidence of COVID-19 cases, stratified by age.

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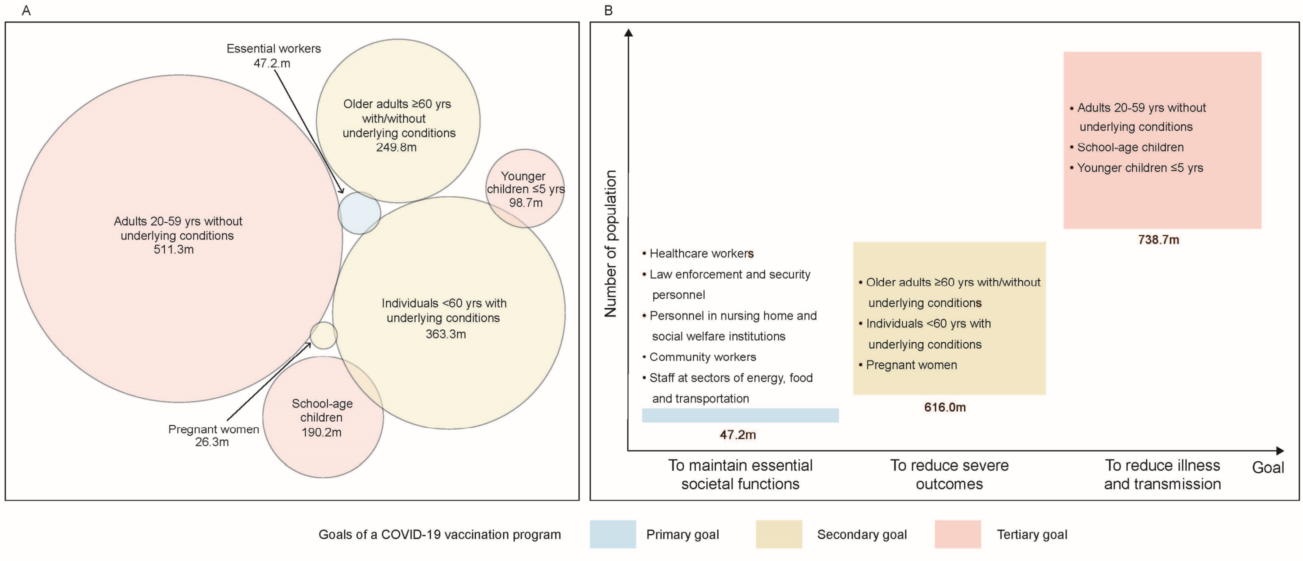

404 **Figure 3**. Estimated size of target population for the COVID-19 vaccination program by goal.
405 A: Overlap of target population groups. B: Estimated number of targeted individuals excluding
406 the overlaps between groups. Note that m denotes million.

407

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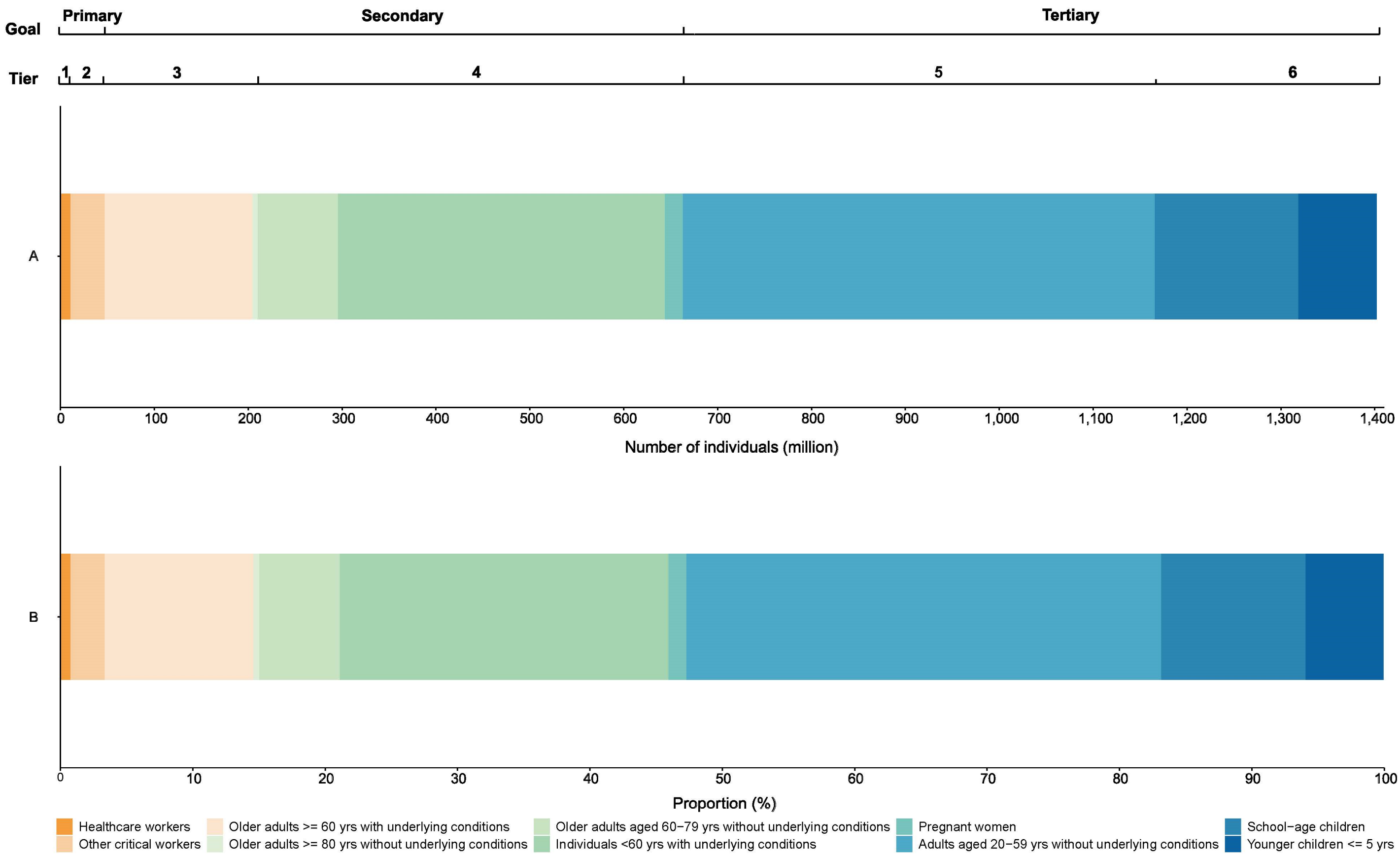
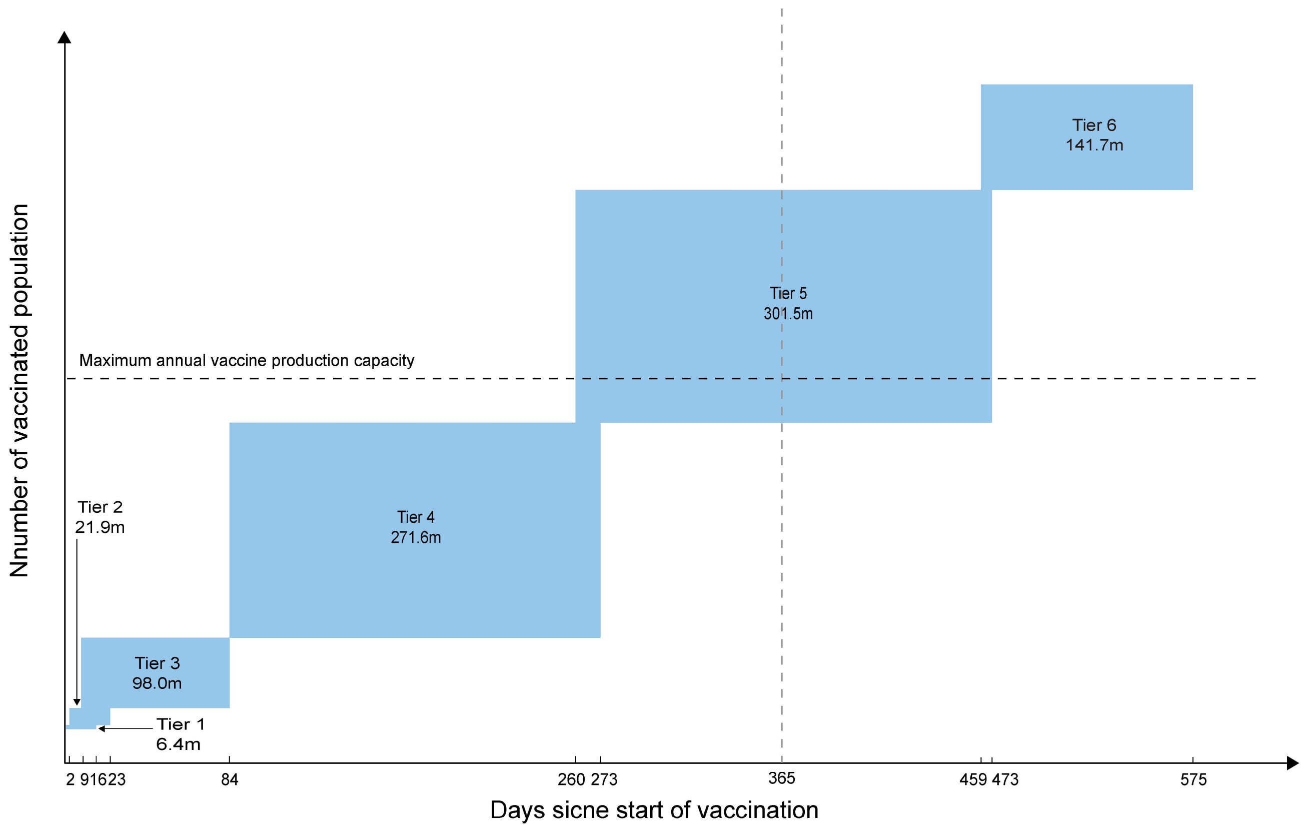


Figure 4. Estimated size of target population for the COVID-19 vaccination program by population group. A: number of individuals, B: proportion. Note that the overlaps between groups were excluded.



414 **Figure 5**. Days needed to vaccinate 60% of the target population, stratified by vaccination tier,
415 under the assumption that three million doses are administered per day. Note that values
416 reported within the square (e.g., 135.8m) denote 60% of the population size in each tier; m
417 denotes million.

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Author Contributions

H.Y. conceived, designed and supervised the study. J.Y., W.Z., H.S., X.Y., K.D., Q.Y., G.Z., H.G. and Z.C. participated in data collection. J.Y., W.Z., H.S., X.Y., K.D., and Q.Y. analyzed the data, and prepared the tables and figures. J.Y. prepared the first draft of the manuscript. H.Y., M.J., C.V., and M.A. commented on the data and its interpretation, revised the content critically. All authors contributed to review and revision and approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Conflict of interest

H.Y. has received research funding from Sanofi Pasteur, GlaxoSmithKline, Yichang HEC Changjiang Pharmaceutical Company, and Shanghai Roche Pharmaceutical Company. M.A. has received research funding from Seqirus. None of those research funding is related to

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COVID-19. All other authors report no competing interests.

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