COVID-19 Vaccination Program in China: a Subnational Descriptive Analysis on Target Population Size and Current Progress

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Research Article

Keywords: Novel coronavirus disease 2019, vaccination, target population, China

Posted Date: June 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-624719/v1

Abstract

Introduction: China is facing substantial risks of imported COVID-19 cases and a domestic resurgence in the long run, and COVID-19 vaccination is expected to be the long-lasting solution to end the pandemic. We aim to estimate the size of the target population for COVID-19 vaccination at the provincial level and summarize the current progress of vaccination programs, which could support local governments in the timely determination and adjustment of vaccination policies and promotional measures.

Methods: By extracting provincial-stratified data from publicly available sources, we estimated the size of priority target groups for vaccination programs and further characterized the ongoing COVID-19 vaccination program at the provincial level, including the total doses administered, the coverage rate, and the vaccination capacity needed to achieve the target coverage of 70%.

Results: The size of the target population shows large differences among provinces, ranging from 3.5 million to 115.2 million. As of June 10, the speed of vaccine roll-out differs remarkably as well, with the highest coverage occurring in Beijing and Shanghai, where 69.8% and 62.3% of the population is fully vaccinated, respectively. However, in 19 of 31 provinces, less than 40% of the population was administered at least one dose, in 9 of which the proportion was even less than 30%. Compared to the routine vaccination capacity before the COVID-19 pandemic, the COVID-19 vaccination capacity has greatly improved. Nevertheless, the current vaccination capacity is far lower than the target of 70% coverage by the end of 2021 or by mid-2022 in approximately 5%-20% of provinces, particularly the Guizhou, Yunnan, Xinjiang, Fujian and Hebei provinces.

Conclusions: Large disparities exist in the target population size and vaccination progress across provinces in China. Vaccine coverage is far from meeting the herd immunity threshold, and the vaccination service capacity needs to be further improved.

Introduction

The coronavirus disease 2019 (COVID-19) pandemic still rages on and has caused immeasurable suffering and loss. Owing to effective non-pharmaceutical interventions (NPIs), China achieved outstanding success in the first round of fighting COVID-19 that emerged in Wuhan [1]. Thereafter, since almost the entire population is still susceptible to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [2], China is facing substantial risks of both imported COVID-19 cases and a domestic resurgence in the long run, with over 16 outbreaks of varying scales (from dozens to hundreds of COVID-19 cases reported) occurring frequently in the past year [3]. Relying on stringent NPIs, such as citywide nucleic acid testing and travel restriction [4–6], these local outbreaks were quickly contained. However, NPIs alone are unable to contribute to achieving herd immunity.

COVID-19 vaccination, which has been implemented in over 200 countries/regions, is expected to be the long-lasting solution to end the pandemic [7]. Israel is leading the world with COVID-19 vaccinations, with 59.4% of the population fully vaccinated as of June 10, 2021[7]. Based on the current vaccination pace,

the United States and the United Kingdom could reach the threshold of herd immunity (70%~90%) by this summer [8–10]. In China, seven COVID-19 vaccines have been approved for emergency/conditional use, with an additional 14 in clinical trials [11, 12]. The COVID-19 vaccine rollout launched in December 2020 [13]. As of June 10, 845.3 million doses were administered [14].

As the most populous country, China aims to vaccinate 70%-80% of its population (0.9 to 1 billion) between the end of 2021 and mid-2022 [15]. Achieving this goal within such a short period is a major challenge for the Chinese Immunization System. Estimating the target population size is crucial to assist policy-making on COVID-19 vaccine deployment. A previous study quantified the national target population size in China and estimated the time it will take to achieve target coverage given an assumption of vaccination capacity (i.e., average daily doses administered) [16]. Due to the large variations in population size and vaccination capacity across provinces, the challenge of achieving the above goal varies. Here, we aim to estimate the size of the target population for the COVID-19 vaccination at the provincial level and the relevant demand for vaccination capacity to achieve the aforementioned goal as well as further identify the gaps between demand and current vaccination capacity in the National Immunization Program (NIP).

Methods

Definition of the priority target population for the COVID-19 vaccination program

When the first COVID-19 vaccines are licensed, there is an urgent need to define priority groups for vaccination due to the supply shortage. Three phased goals have been clearly defined and previously endorsed. [16, 17] The primary goal is to maintain the essential functions of society. Therefore, essential workers should be vaccinated as the first priority, including, but not limited to, healthcare workers, social security workers, caregivers in social welfare institutions, community workers, personnel producing and supplying daily necessities, and individuals studying/working overseas. These individuals should be considered because of their importance to continuing the functioning of core services and their risk of SARS-CoV-2 infection in an occupational environment.

The secondary goal is to protect the high-risk population, which is more vulnerable to severe clinical illness once infected, including people with underlying conditions, older adults and pregnant women [16, 17]. Considering variations in susceptibility to SARS-CoV-2 infection across age groups[18], we further categorized people with underlying conditions into 1) people aged 60 or over with at least one underlying condition and 2) people aged < 60 with at least one underlying condition. We categorized people without underlying conditions into 1) people aged 80 or over without any underlying condition and 2) people aged 60–79 years old without any underlying condition.

The tertiary goal is to contain SARS-CoV-2 transmission, thus the target population includes other individuals under 60 years of age without underlying conditions, i.e., working-age people (18–59 years),

school-aged children (6–17 years) and younger children (0–5 years). The detailed definition of priority groups is presented in Additional file 1: Table S1.

Estimating the target population size

The number of essential workers and people studying/working abroad are extracted from statistical yearbooks (i.e., Economic Census Yearbook, Civil Affairs Statistical Yearbook, Tabulation data on Population Census, Educational Statistics), the White Paper on China's National Defense, concise statistics from the Ministry of Commerce, paper books and theses [19–25]. Age-specific population size was obtained from National/Provincial Statistical Yearbooks [26]. The number of pregnant women is the sum of live births, abortions, still births and fetal deaths, which was obtained from the Health Statistical Yearbook, Population & Employment Statistics Yearbook and previous literature [27, 28].

People with these underlying conditions are considered to have a high risk of severe outcomes of COVID-19, including respiratory diseases, cardiovascular system diseases, chronic liver diseases, chronic kidney diseases, nervous system diseases, diabetes mellitus, cancers, tuberculosis, the human immunodeficiency virus/acquired immunodeficiency syndrome, sickle cell disorders and a body mass index ≥ 30. We extracted the prevalence of individuals with specific underlying conditions in China stratified by age and geographic region (Eastern, Central and Western China, details in Additional file 1: Figure S1) from the Global Burden of Diseases, Risk Factors, and Injuries Study in 2019 and the National Health Services Survey in 2013 [29, 30]. Then we estimated the probability of having at least one of these conditions as 1 minus the probability of not having a condition in any of the aforementioned diseases and multiplied the ratio between the observed and expected percentage of individuals with at least one condition[31]. We further multiplied the estimated geographic-region specific probability by the population size of provinces in relevant provinces to produce the number of individuals with any of these conditions.

Some individuals are classified into more than one group/tier. Under this circumstance, he/she will be sorted into the highest priority when estimating the population size. Details about the data source are presented in Additional file 1: Table S1.

Progress of COVID-19 vaccination by province

From December 2020 to March 14, 2021, the Chinese government periodically reported the total vaccine doses administered at the national level, and the vaccination doses administered have been reported on a daily basis since March 23, 2021. We collected data on administered doses through official sources (i.e., government websites, health commissions, press conferences) and unofficial sources (i.e., interviews with government officials or persons in charge) by province and the Chinese government. Some provinces report the number of people who receive at least one dose and are fully vaccinated. For provinces that did not report this information, we estimated the maximum proportion of the population that received at least one dose and of the fully vaccinated population. The vaccines currently in use in China require 1, 2 or 3 doses, depending on different platforms [32]. Because the actual supply of each vaccine is still unavailable, we assumed a two-dose vaccination schedule for estimating coverage.

At the provincial level, the vaccine doses administered are reported irregularly. We estimated the maximum single-day vaccination capacity by calculating the maximum slope of every two adjacent vaccine dose data points. China established a domestic target of vaccinating 40% of the population by June 2021 [33] and vaccinating 70% of the population between the end of 2021 and mid-2022. Then we analyzed the expected vaccination doses per day and identified the service gap by province compared to their routine vaccination capacity (see below).

Routine vaccination capacity by province

The race to roll out COVID-19 vaccines depends on local vaccination capacity. Here, we estimated the provincial-stratified average daily vaccine doses administered before the COVID-19 pandemic, including both free vaccines in the National Immunization Program (NIP vaccines) and self-paid vaccines that have not been introduced into the NIP (non-NIP vaccines). This daily average represents the routine vaccination capacity of the immunization system. The administered doses of NIP vaccines are the product of live births and reported coverage [34]. The coverage of NIP vaccines by province was extracted from government public reports (i.e., Statistical Surveillance Report on Child Development Planning, health statistics data or population health reports) and published literature. The administered doses of non-NIP vaccines in 2014[35] were used as a proxy for those before the COVID-19 pandemic.

Results

Target population size of COVID-19 vaccination by province

The national target population is 1.4 billion. From Goal 1 to Goal 3, a total of 48.3 million, 533.3 million and 822.2 million individuals were included in the vaccination program, respectively. The size of the target population shows large differences among provinces, ranging from 3.5 million to 115.2 million (Fig. 1, Figure S2 and Additional file 1: Table S2). Guangdong province has the largest proportion of the total population. Shandong and Henan provinces rank second and third, accounting for similar shares of 7.2% and 7%, respectively. In contrast, Tibet, Qinghai, Ningxia and Hainan provinces have a relatively low share of less than 1%.

Under the primary goal, Shandong (4.3 million, 9.0%) and Guangdong (4.0 million, 8.2%) provinces have the largest number of essential workers, while Tibet has only 0.3% of healthcare staff and other critical workers in the country. The first eight provinces (Shandong, Guangdong, Henan, Jiangsu, Sichuan, Hebei, Hubei, Zhejiang) together account for 49.2% of the target population of the primary goal. We observed a similar distribution in the target population of the secondary and tertiary goals (Fig. 1 and Additional file 1: Table S3). There was an obvious linear relationship between the size of the target population groups and the total population (see in Additional file 1: Figure S3).

Current progress of COVID-19 vaccination and capacity gaps by province

At the initial stage of the COVID-19 vaccination program, the daily doses administered at the national level were very low (< 4 million before March 31) and then increased to an average of 4.8 million during April. Since May, the daily doses administered significantly increased and have stabilized at more than 10 million since May 12. The maximum daily doses administered reached 22.9 million on June 2 (Fig. 2). As of June 10, a total of 845.3 million doses were administered in mainland China (covering approximately 30.1% of the entire population), with a median of 18.6 (interquartile range: 9.3–29.4) million doses administered at the provincial level. The four provinces with the highest doses administered (more than 40 million doses) included Guangdong, Shandong, Zhejiang and Hubei (Fig. 3A-B). The coverage of people who were administered at least one dose was highest in Shanghai, Tianjin and Beijing, which was over 80%. The coverage of the fully vaccinated population was highest in Beijing, Shanghai and Hainan, which was 60%-70%. However, the coverage in other provinces lags far behind. In 9 of 31 provinces, less than 40% of the population was administered at least one dose as of June 10, with the lowest rates (< 5%) in Xinjiang (Fig. 3C-D).

Before the COVID-19 pandemic, the routine vaccination capacity in China was approximately 1.4 million doses per day, equivalent to an average of 1,000 doses per million population per day, with the highest vaccination capacity in Guangxi (1439 doses per million population per day) and the lowest vaccination capacity in Heilongjiang (380 doses per million population per day) (Fig. 4A). In more than half of the provinces, the daily vaccination capacity is between 800 and 1,100 doses per million population (Fig. 4A). To achieve a coverage of 40% by June at the provincial level, the average service capacity needs to be increased by 3 to 11 times on the basis of routine capacity (Fig. 4A). By early June, only Beijing, Shanghai, Tianjin, Hubei, Guangdong and Hainan provinces had achieved the expected daily doses, whereas the other provinces still faced a daily shortfall of average service capacity, ranging from 1500 doses in Zhejiang to 0.2 million doses in Hebei province (Fig. 4B). Even in terms of the maximum daily vaccination doses, three provinces did not achieve the expected daily doses.

To vaccinate 70% of individuals by the end of 2021 or by mid-2022, on the basis of the maximum daily vaccination doses during December 2020 and May 2021, 26 or 29 provinces could achieve the goal, respectively. Large gaps have been observed in Xinjiang, Yunnan, Fujian and Hebei (Fig. 5). On the basis of the average vaccination speed after mid-April as service capacity, 25 or 28 provinces could achieve the goal (see in Additional file 1: Figure S4).

Discussion

We quantified the size of the target population groups of COVID-19 vaccination stratified by province in China. The size of the target population shows large differences among provinces, ranging from 3.5 million to 115.2 million. To achieve the goal of vaccinating 40% of the target population by June 2021, the COVID-19 vaccination capacity (daily doses administered) has been highly improved compared to the routine vaccination capacity before the COVID-19 pandemic. Nevertheless, the speed of vaccine roll-out differs remarkably at the provincial level. The highest coverage occurs in Beijing and Shanghai (over 80% of the population was administered at least one dose, equivalent to 69.8% and 62.3% of the

fully vaccinated population, respectively). However, in 9 of 31 provinces, less than 30% of the population was administered at least one dose by early June. The current vaccination capacity (even in terms of maximum daily doses administered) is far less than enough to achieve the target of 40% coverage by June in three provinces. Even on the basis of the maximum daily vaccination doses from December 2020 to May 2021, approximately 5 and 2 provinces will be unable to reach the vaccine target of 70% by the end of 2021 and the middle of 2022, respectively.

The Joint Prevention and Control Mechanism of the State Council in China released a three-step strategy for the COVID-19 vaccine rollout [13] on December 15, 2020. In the first step, nine groups of essential workers, aged 18 to 59, were prioritized because of their high risk of occupational exposure. In the second step, vaccination programs would focus on key populations that are vulnerable to severe outcomes once infected, including older adults aged ≥ 60 and people with underlying conditions. In the final step, vaccines are available to other general populations. The vaccination program has been gradually extended to residents aged 18–59 since approximately March 2021 and further extended to people over 60 since March 29, 2021 [32]. To vaccinate 40% of the population by June 2021 and 70% of the population by the end of 2021 or mid-2022, China invested significant efforts into promoting coverage. Estimating the size of target priority groups at the provincial level could support local governments to determine the coverage rate stratified by target groups, and thus to timely determine and adjust vaccination policies and promotional measures.

Currently, COVID-19 vaccines are ineligible for pregnant women. In developed countries, such as the United States, pregnant women have been recommended to receive the vaccine, even with limited data on safety and efficacy [36, 37]. Clinical trials in pregnant women have been launched for several vaccines abroad [38]. In our analysis, we considered pregnant women as a target population group, accounting for the increased risk of severe illness among pregnant women, such as preterm delivery [39]. However, high vaccine hesitancy among pregnant women, which occurs in influenza vaccination in China [40, 41], will most likely be a major challenge for the implementation of COVID-19 vaccination in this group, even though the vaccine has been proven to be safe and effective in the future. If we exclude pregnant women from vaccination, the target population size in each province would decrease by approximately 1.8%.

To accelerate the COVID-19 vaccination and achieve herd immunity as early as possible, a series of measures have been implemented across China, including setting up temporary inoculation points, extending the service hours of inoculation points and even opening night vaccination sites, and rolling out mobile vehicles and even offering vaccines door-to-door for those with poor geographical access. [42] Under the joint efforts of central and local governments, the daily vaccination doses have exceeded 15 times the routine capacity (22.9 million vs. 1.4 million). Nonetheless, great disparities exist in vaccination progress across provinces. For example, more than half of the residents in Beijing and Shanghai have been fully vaccinated, whereas the one-shot vaccination proportion is so far around 30% in most provinces. The disparities could be largely determined by the national vaccination strategy at the previous stage. Priority is given to areas with higher risks of COVID-19 outbreaks [43], such as Beijing and

Shanghai, which are characterized as the largest port cities and the most populous and largest megacities.

Our findings show that COVID-19 coverage until now has been very low in some provinces. It is a major challenge to achieve the coverage targets of 40% and 70% within the specified timeframe, particularly for provinces with large populations (e.g., Henan and Hebei provinces). When and to what extent we could remove NPIs does not depend on the time when the provincial-level vaccine coverage first reaches the herd immunity threshold, but the time when the last province reaches the herd immunity threshold. The earlier removal of NPIs in provinces with high vaccine coverage (always developed regions with better healthcare services) definitely increases the risk of the transmission of SARS-CoV-2 in other provinces with low vaccine coverage, which have limited healthcare resources and poor healthcare accessibility.

In addition to the aforementioned national vaccination strategy, other factors, such as the vaccine supply, varying strengths of local implementation measures and the willingness to receive the COVID-19 vaccination, could also influence vaccination progress. The domestic production capacity is expected to reach 5 billion doses this year [44], thus vaccine supplies would be adequate. The vaccine hesitancy rates varied among provinces and were above 30% in 20 provinces [45]. The skyrocketed increase in the number of local populations that received the vaccination after COVID-19 outbreaks occurred in Anhui and Guangdong provinces [46], indicating that stimulating people to receive the vaccination would be crucial to achieving herd immunity as soon as possible.

In this study, we estimate the vaccination capacity needed to reach a coverage target of 70%. Note that it is not a precise estimate of the herd immunity threshold. Instead, it is estimated on the basis of the well-known Eq. $(1 - 1/R_0)/VE$[47], where R_0 is the basic reproduction number and VE denotes vaccine efficacy. It ignores heterogeneities that can make these figures biased in specific locations, including social mixing patterns and age-specific susceptibility. Accordingly, it has been highlighted that the provinces could not stop the vaccination when reaching the target coverage of 70%. Further modeling studies are needed to determine the exact herd immunity threshold and when and to what extent we could remove NPIs for specific regions.

Several limitations of our study should be mentioned. First, some provinces only announced their cumulative administered doses. To estimate the number of people who are fully vaccinated, we assume a uniform two-dose schedule and simplistically divide the overall doses by two. However, the available data in some provinces indicate that the proportion of individuals receiving the first dose is much higher than the proportion receiving the second dose. Accordingly, we might overestimate the proportion of people who are fully vaccinated. Second, only Beijing and Shanxi established a system to report daily vaccination status [48, 49]. For other provinces, we manually collected information through several search engines, which may affect our data integrity. Accordingly, the maximum service capacity is probably a conservative estimate, due to scarce data points for provinces, such as Heilongjiang, Jiangsu, Fujian, Yunnan, Tibet and Xinjiang.

Conclusions

Our study quantified the size of priority groups for COVID-19 vaccination stratified by provinces in China. We further provided a landscape for current progress in COVID-19 vaccination and capacity gaps across China. The findings show that China has made great strides in the vaccination speed since the start of the vaccine roll-out in late 2020. However, great disparities exist in vaccination progress across provinces. Even on the basis of the maximum daily vaccination doses from December 2020 to May 2021, 5 provinces will be unable to reach the vaccine target of 70% by the end of 2021, and 2 provinces still cannot achieve the goal by the middle of 2022. In addition to further improving vaccination service capacity, exploring effective strategies and measures to encourage people to get vaccinated would be crucial.

Abbreviations

COVID-19: coronavirus disease 2019; NPIs: non-pharmaceutical interventions; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2; NIP: National Immunization Program.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study will be available on GitHub when it is accepted for publication.

Competing interests

H.Y. has received research funding from Sanofi Pasteur, GlaxoSmithKline, Yichang HEC Changjiang Pharmaceutical Company, and Shanghai Roche Pharmaceutical Company. None of this research funding is related to COVID-19. All other authors report no competing interests.

Funding

The study was supported by grants from the National Science Fund for Distinguished Young Scholars (No. 81525023, H.Y.) and the Key Emergency Project of Shanghai Science and Technology Committee (No 20411950100, H.Y.). The funders had no role in the study design, data collection and analysis; the decision to publish; or the preparation of the manuscript.

Author contributions

H.Y. conceived the study. H.Y. and J.Y. designed and supervised the study. W.Z., X.Y., Z.Z. and J.Y. participated in data collection. W.Z. and J.Y. analyzed the data and prepared the tables and figures. W.Z. prepared the first draft of the manuscript. J.Y. and H.Y. commented on the data and its interpretation and critically revised the content. 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.

Acknowledgements

Not applicable.

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Figures

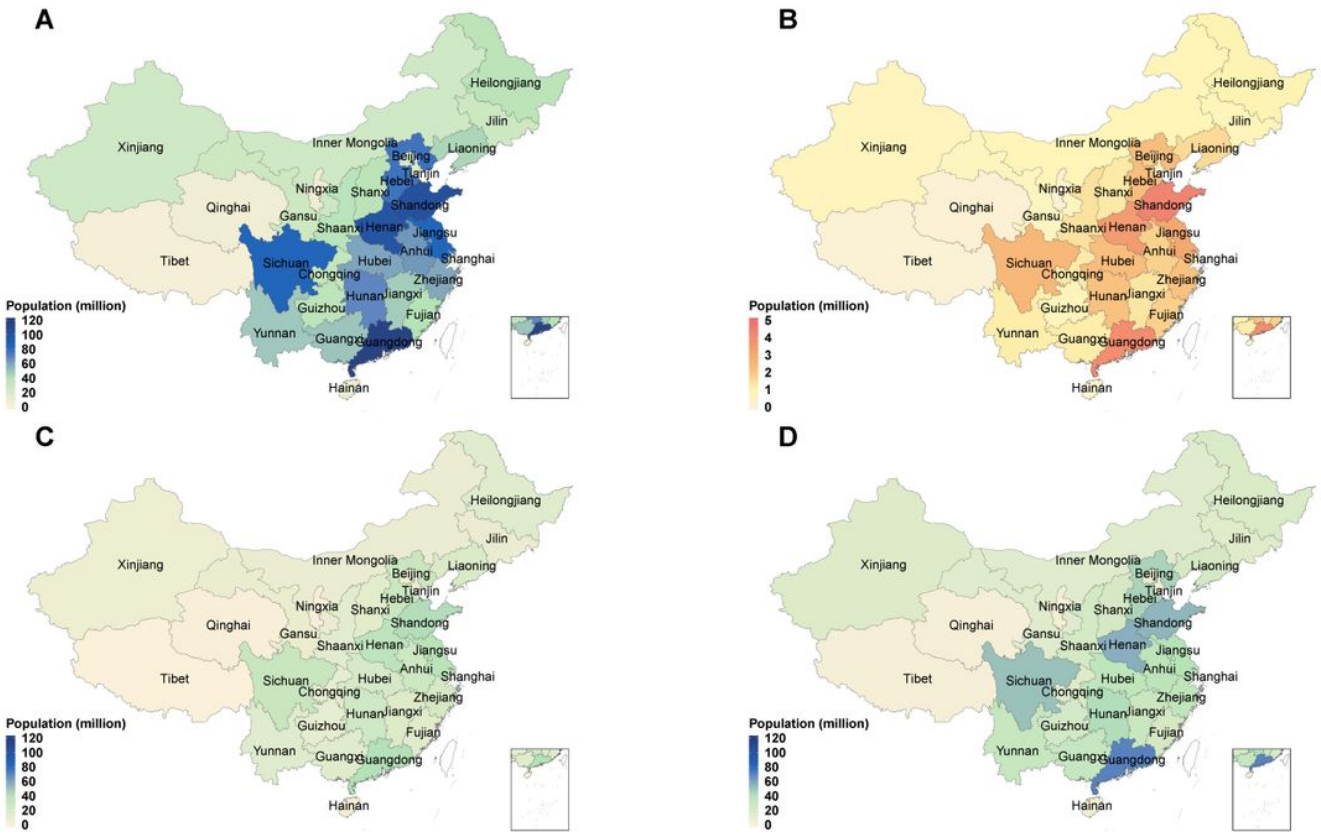

Figure 1

The size of the target population for the COVID-19 vaccination program, stratified by province. A: Overall population. B: The target population size for maintaining the essential functions of society, including healthcare workers and social security workers. C: The target population size for protecting the high-risk population, including people with underlying conditions, older adults and pregnant women. D: The target population size for containing SARS-CoV-2 transmission, including working-age people, school-aged children and younger children. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

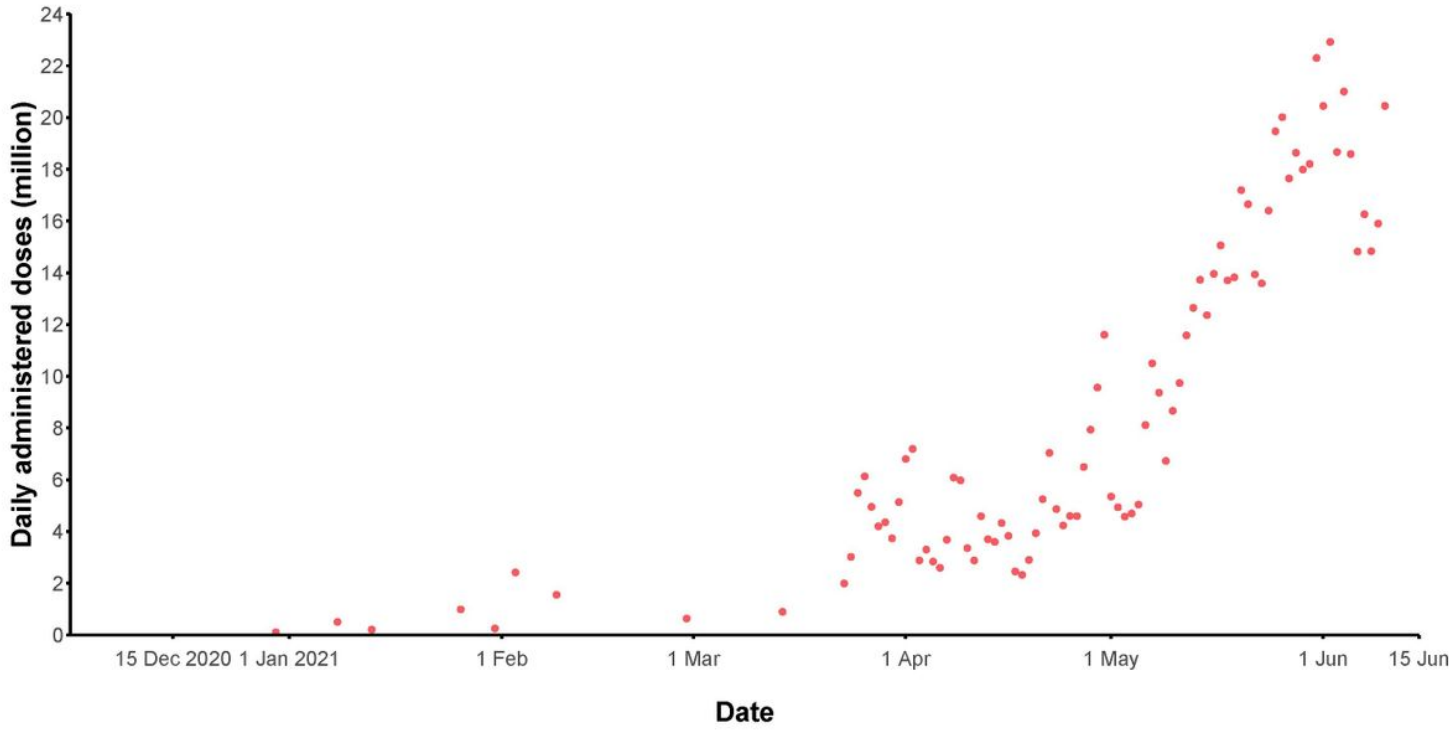

Figure 2

Daily vaccination doses in mainland China between November 30, 2020 and June 10, 2021.

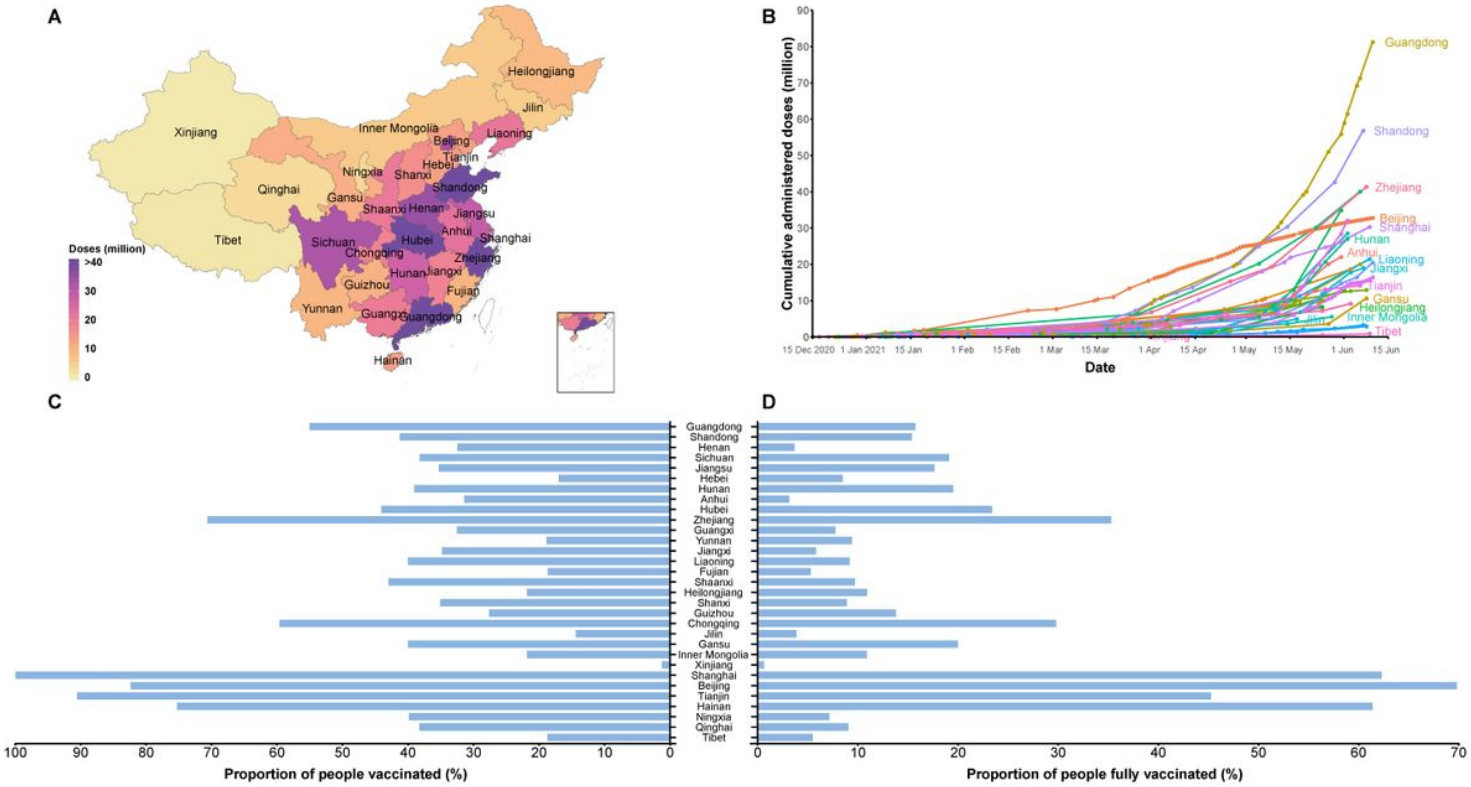

Figure 3

Current cumulative administered doses, vaccination progress and coverage of COVID-19 vaccination program in mainland China. A: Cumulative administered doses as of June 10, 2021. B: Time series of administered doses between December 15, 2020 and June 10, 2021. C: The share of the population receiving at least one dose against COVID-19 as of June 10, 2021. D: The share of the population fully vaccinated against COVID-19 as of June 10, 2021. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

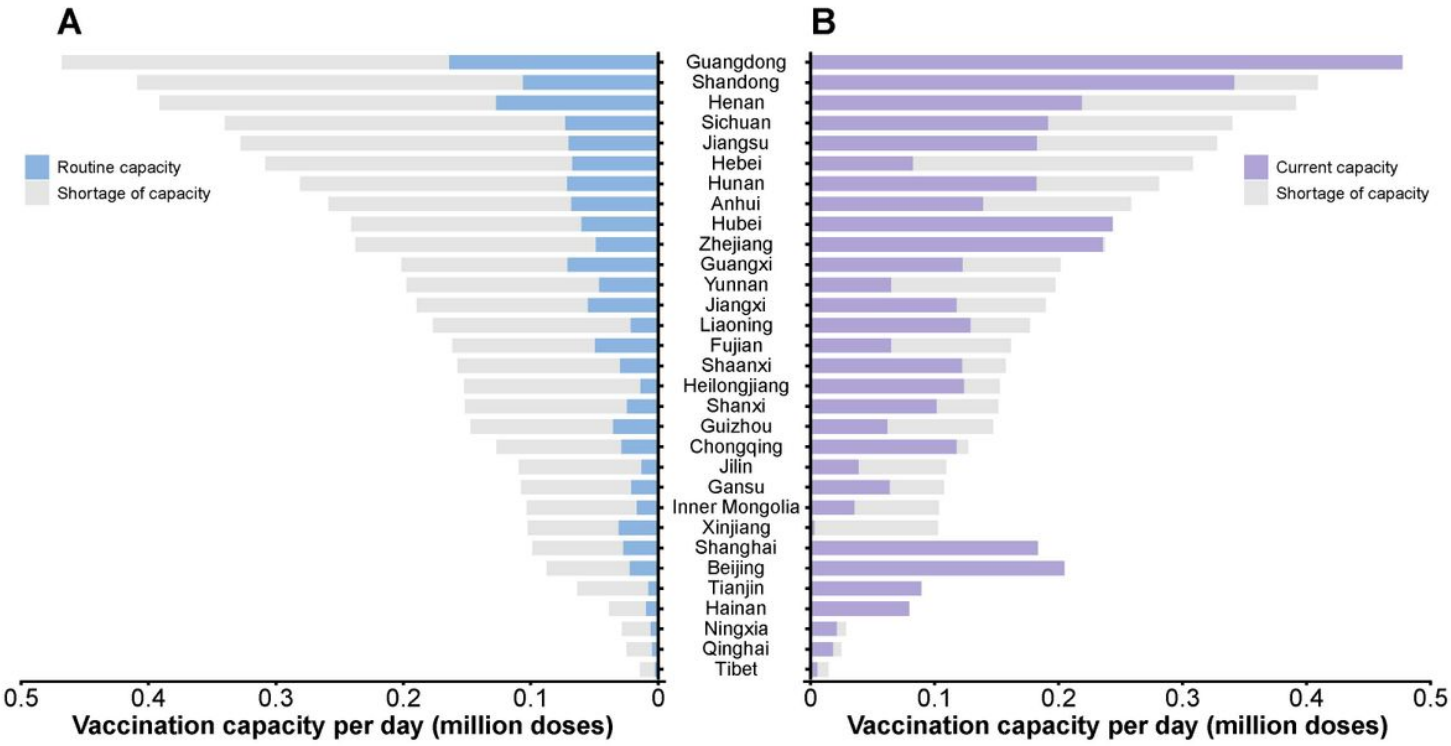

Figure 4

Service capacity gaps to vaccinate 40% of the target population by June 2021. A: The routine daily capacity before the COVID-19 pandemic and service gaps. B. The current average daily capacity and service gaps.

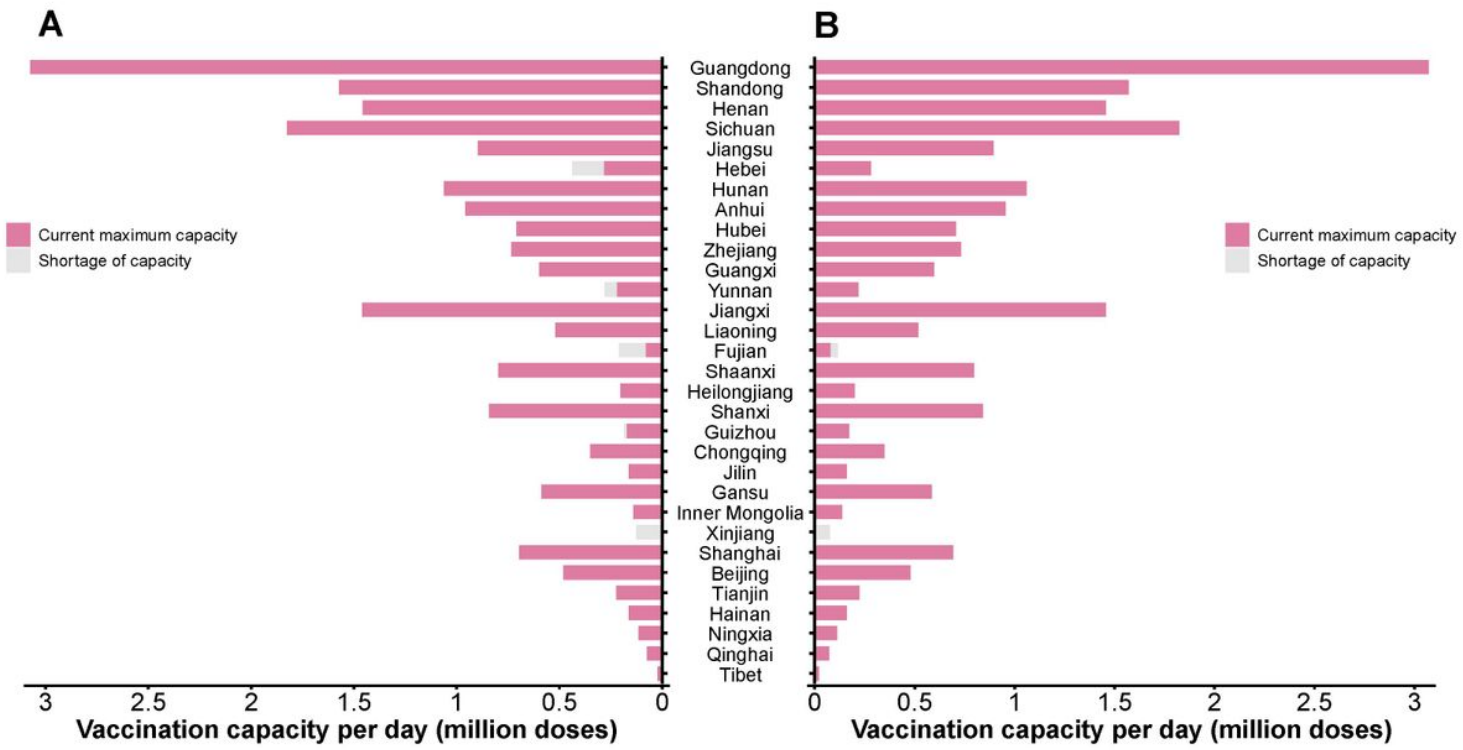

Figure 5

Service capacity gaps to vaccinate 70% of the target population by 2021 or mid-2022. A: The current maximum single-day capacity and service gaps by the end of 2021. B: The current maximum single-day capacity and service gaps by mid-2022.

Supplementary Files

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