



The Demand for Inpatient and ICU Beds for COVID-19 in the US: Lessons From Chinese Cities

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1 **The demand for inpatient and ICU beds for COVID-19 in the US: lessons from Chinese**
2 **cities**

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19 **Keywords:** outbreak, emerging infectious disease, coronavirus, disease control,
20 nonpharmaceutical interventions, critical care, hospitalization, vulnerable populations

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26 **Key points**

27 **Question:** What hospital capacity is needed to respond to outbreaks of SARS-CoV-2 in US
28 cities, and how does this depend on intervention timing?

29 **Findings:** If a Wuhan-like outbreak were to occur, 24.5 inpatient beds and 2.6 ICU beds per
30 10,000 adults would be needed during the peak epidemic; earlier intervention vastly reduces
31 this.

32 **Meaning:** Strict disease control strategies are needed early to mitigate the demand for inpatient
33 and ICU beds.

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36 **Abstract**

37 **Importance:** Sustained spread of SARS-CoV-2 has happened in major US cities. Capacity
38 needs in Chinese cities could inform the planning of local healthcare resources.

39 **Objective:** To describe and compare the intensive care unit (ICU) and inpatient bed needs for
40 COVID-19 patients in two Chinese cities. To estimate the peak ICU bed needs in US cities if a
41 Wuhan-like outbreak occurs.

42 **Design:** Observational study

43 **Setting:** Wuhan and Guangzhou, China

44 **Participants:** Confirmed COVID-19 patients in Wuhan and Guangzhou from January 10 to
45 February 29, 2020.

46 **Exposure(s):** Timing of disease control measures in relation to the timing of SARS-CoV-2
47 community spread.

48 **Main Outcome(s) and Measure(s):** Total number of critical and severe patient-days and the
49 peak number of critically- and severely-ill patients over the study period.

50 **Results:** In Wuhan, strict disease control measures were implemented six weeks after
51 sustained local transmission of SARS-CoV-2. Between January 10 and February 29, COVID-19
52 patients accounted for an average of 637 ICU patients and 3,454 serious inpatients on each
53 day. During the epidemic peak, 19,425 patients (24.5 per 10,000 adults) were hospitalized,
54 9,689 (12.2 per 10,000 adults) were considered to be in serious condition, and 2,087 patients
55 (2.6 per 10,000 adults) needed critical care per day. In Guangzhou, strict disease control
56 measures were implemented within one week of case importation. Between January 24 and
57 February 29, COVID-19 accounted for an average of 9 ICU patients and 20 inpatients on each
58 day. During the epidemic peak, 15 patients were in critical condition, and 38 were classified as
59 serious. If a Wuhan-like outbreak were to happen in a US city, the need for healthcare
60 resources may be higher in cities with a higher prevalence of vulnerable populations.

61 **Conclusions and Relevance:** Even after the lockdown of Wuhan on January 23, the number of
62 seriously ill COVID-19 patients continued to rise, exceeding local hospitalization and ICU
63 capacities for at least a month. Plans are urgently needed to mitigate the effect of COVID-19
64 outbreaks on the local healthcare system in US cities.

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71 **Introduction**

72 In the two months since the first report of four cases of atypical pneumonia in Wuhan,
73 Hubei, China on December 27, 2019,¹ the cumulative number of confirmed cases of COVID-19
74 in the city has risen to 49,122, with 2,195 deaths from the disease by the end of February,
75 2020.² On January 23, Wuhan city shut down in response to the fast-evolving epidemic. All
76 public transportation within, to and from the city was suspended, and residents were barred
77 from leaving. An estimated nine million people remained in the city after the lockdown.³ Strict
78 social distancing measures were also implemented, including the compulsory wearing of face-
79 masks in public.

80 During the early phase of the response in Wuhan, the number of patients overwhelmed
81 local fever clinics and hospitals designated to receive COVID-19 patients. The media reported a
82 significant shortage of hospital beds, intensive care unit (ICU) beds, and other healthcare
83 resources. By February 12, over eighteen thousand health care workers were sent to Wuhan
84 from other parts of China to help with the coronavirus response.⁴ Forty eight hospitals (including
85 two new hospitals built specifically for COVID-19 patients) and over 26,000 inpatient beds were
86 designated for the isolation and treatment of patients with confirmed SARS-CoV2. Quarantine
87 centers with over 13,000 total beds were also established to isolate confirmed patients with
88 milder illnesses. By the end of February, the local government reported that “finally patients
89 don’t need to wait for beds. Now the beds are waiting for patients.”⁵

90 With human-to-human transmission now established in other countries, mitigating the
91 potential impact of COVID-19 on local healthcare systems is a top priority. A recent clinical
92 study from China reported that 81% of patients in whom SARS-CoV-2 is detected experience
93 mild disease, 14% severe disease and 5% critical disease.¹ However, questions still remain as
94 to the proportion of asymptomatic patients and the clinical course of the disease, preventing
95 accurate prediction of hospitalization and ICU needs using transmission models.

96 Here, we describe the ICU and hospitalization needs for COVID-19 in two Chinese
97 cities: Wuhan, the epicenter of China's outbreak, and Guangzhou, a Chinese metropolis that
98 experienced early importation of cases. As with all Chinese cities, strict social distancing
99 measures and contact tracing and quarantine protocols were implemented since late January in
100 Guangzhou, which resulted in much smaller outbreak size than Wuhan. Describing and
101 comparing the resource needs in both cities may serve as benchmarks to help other large
102 metropolises in the world prepare for potential outbreaks.

103

104 **Methods**

105 We extracted and estimated confirmed COVID-19 case counts for severe and critical
106 cases from Wuhan and Guangzhou from situation updates from Chinese national and local
107 health commissions. We extracted the number of designated COVID-19 beds and
108 hospitalizations from the Wuhan Municipal Health Commission website.

109 A confirmed COVID-19 case was considered severe if the patient experienced at least
110 one of the following: dyspnea, respiratory frequency ≥ 30 /minute, blood oxygen saturation $\leq 93\%$,
111 arterial blood oxygen partial pressure (PaO₂) to oxygen concentration (FiO₂) ratio < 300 mmHg,
112 and/or a pneumonia patient showing significant progression of lesions infiltrating $> 50\%$ of the
113 lung field on chest imaging within 24-48 hours. A confirmed patient was considered to be critical
114 if he/she experienced respiratory failure demanding invasive and/or non-invasive ventilation for
115 respiratory support, septic shock, and/or with multiple organ dysfunction/failure demanding
116 intensive care.^{6,7} These definitions have been more detailed with revisions of the Chinese
117 diagnostic and treatment guidelines. In this study, we used the term *serious* patients to describe
118 severe and critical patients collectively. We estimated the number of prevalent severe and
119 critical cases cross-sectionally per day - allowing for the fact that patients could move in and out
120 of these categories over the course of their disease.

121 We extracted Wuhan city and Hubei province COVID-19 data between January 10 and
122 February 29, including the numbers of confirmed cases, new cures, new deaths, severe cases,
123 critical cases, serious cases (a sum of severe and critical cases), cumulative cures, cumulative
124 deaths, cumulative confirmed cases, and currently confirmed cases (cumulative confirmed
125 cases - deaths - cures). If official sources did not have data for variables on some dates, we
126 calculated the number of cases based on the relationships between variables. Because Wuhan
127 did not systematically report the number of severe and critical cases, we estimated these
128 numbers by assuming that the proportions of serious and critical cases out of all currently
129 confirmed cases was the same in Wuhan as in the rest of Hubei. For the dates when it was not
130 possible to estimate the severe and critical case counts using the above methods (January 18,
131 25, and 27), we assumed the number of severe and critical cases on those dates were the
132 same as reported for the previous day.

133 For Guangzhou, we extracted the city's case count on the number of confirmed, severe,
134 clinical, and cured cases and deaths for each day between January 24 and February 29.

135

136 *Statistical analysis*

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138 We summed the total patient-days under critical and/or severe condition to estimate the
139 total ICU-days and serious-inpatient-days. We plotted the raw number of patients in critical and
140 severe conditions and patients hospitalized on each day for Wuhan and Guangzhou, and
141 estimated the proportion of hospitalization and ICU admission per 10,000 adults based on the
142 assumption that there were 9 million people present in Wuhan during the lockdown,³ of whom
143 88.16% were age 15 or above (2010 census for cities in Hubei province), and 14.9 million
144 present in Guangzhou of whom 82.82% were age 15 or above (Guangdong statistical bureau).

145

146 We then projected the number of patients who have severe and critical COVID-19
147 disease at the peak of a Wuhan-like outbreak in the 30 most populous US cities by assuming
148 that the effect of age and comorbidity on patient outcomes would be the same as their effect on
149 COVID-19 mortality as derived from case reports from China until February 11.⁸ Specifically, we
150 estimated the stratum-specific critical care rate in Wuhan by assuming that the risk factor for
151 being in critical care is the same as that for death (age and comorbidities, e.g. hypertension).⁸
152 We estimated the probability of being in critical condition at the peak of the epidemic in each
153 age and hypertension stratum using the COVID-19 mortality rate ratios for age and
154 hypertension⁸ and the proportion of Wuhan population in each stratum. The hypertension
155 prevalence in adults in Wuhan was estimated as 25.7%,⁹ and the proportion of the population
156 aged over 65 years 14.1%.¹⁰ We then applied these stratum-specific critical care rate to the
157 population structures in US cities based on the crude hypertension prevalence in adults in
158 2017¹¹ and the proportion of adult population over 65 years of age in these cities.¹²

159

160 **Results**

161

162 In Wuhan, COVID-19 accounted for a total of 32,486 ICU-days and 176,136 serious-
163 inpatient-days between January 10 and February 29 (**Figure 1**), an average of 637 ICU patients
164 and 3,454 serious inpatients on each day over that 51 day period. During the peak of the
165 epidemic from mid to late February, a maximum of 19,425 patients (24.5 per 10,000 adults)
166 were hospitalized, 9,689 patients (12.2 per 10,000 adults) were considered to be in “serious”
167 condition, and 2,087 patients (2.6 per 10,000 adults) needed critical care per day.

168 In Guangzhou, COVID-19 accounted for a total of 318 ICU-days and 724 inpatient-days
169 between January 24 and February 29 (**Figure 2**), an average of 9 ICU patients and 20
170 inpatients during that 37 day period. During the peak of the epidemic (early February), 15
171 patients were in critical condition, while 38 were hospitalized and classified as serious. Unlike

172 Wuhan, where patients with mild COVID-19 disease were isolated in quarantine centers and not
173 in designated hospitals, all confirmed patients in Guangzhou were hospitalized until cure. The
174 maximum number of hospitalizations in Guangzhou on any day was 271 patients.

175 The projected number of prevalent critically ill patients at the peak of a Wuhan-like
176 outbreak in US cities ranges from 2.1 to 4.0 per 10,000 adults when we took into account of the
177 difference in age distribution (**Figure 3, top**), and from 2.6 to 4.9 per 10,000 adults when we
178 took into account of the differences in comorbidity (hypertension) prevalence (**Figure 3,**
179 **bottom**).

180

181 **Discussion**

182

183 Even after the lockdown of Wuhan on January 23, the number of seriously ill COVID-19
184 patients continued to rise, exceeding local hospitalization and ICU capacities for at least a
185 month. During the peak of the Wuhan epidemic in February, nearly 20,000 COVID-19 patients
186 were hospitalized simultaneously, with 10,000 in severe or critical conditions. If a Wuhan-like
187 outbreak were to take place in a US city, even with strong social distancing and contact tracing
188 protocols as strict as the Wuhan lockdown, hospitalization and ICU needs from COVID-19
189 patients alone may exceed current capacity. The need for healthcare resources may be higher
190 in some US cities where there is a higher prevalence of vulnerable populations (age and
191 comorbidity) than in Wuhan.

192 Exceeding healthcare capacity may increase the community spread of SARS-CoV-2. In
193 Wuhan, home isolation and quarantine were used in the early phase of the epidemic to alleviate
194 the demand in healthcare resources. However, because of the exponential increase of the
195 number of patients who developed serious illness but could not be hospitalized due to capped
196 capacity, secondary transmission in the community continued as patients and their household
197 contacts moved between hospitals seeking care.

198 Exceeding healthcare capacity may also lead to decreased quality of care, such as not
199 being able to get access to a ventilator, which would lead to an increased case fatality ratio. By
200 the end of February, Wuhan's case fatality ratio was 4.5%, 3.2% for the rest of Hubei province,
201 and for the rest of China, where healthcare capacity was not exceeded due to strong social
202 distancing and contact quarantine measures in the early phase of the epidemic (such as
203 Guangzhou), 0.8%.¹³ One contributing factor to the lower case fatality ratio in the rest of China
204 may be higher case ascertainment than Wuhan during the early phase of the epidemic.

205 In both Wuhan and Guangzhou, the lockdowns did not lead to immediate downturns in
206 the demand for hospitalization or the number of serious cases; rather, the peak in these
207 measures occurred approximately a month after the lockdown in Wuhan, and two weeks after
208 the lockdown in Guangzhou. This delay reflects the potentially long time from infection to severe
209 and critical conditions as many COVID-19 patients who eventually require ICU care present
210 initially as having only mild symptoms,¹⁴ and even longer time to discharge or death,¹⁵ resulting
211 in the accumulation of hospitalized cases long after the downturns in the community spread. In
212 Wuhan, the longer delay may also reflect the ongoing transmission after the lockdown described
213 above, which itself resulted from the overloading of the healthcare system.

214 This study has several limitations. We relied on officially reported statistics, which may
215 not represent the change of actual case counts over time, but rather a reflection of testing and
216 hospitalization capacity. The trend in Wuhan of the number of serious cases and
217 hospitalizations is thus not reflective of actual need, but rather the trend in maximum capacity of
218 the Wuhan system in diagnosis and treatment. We are therefore more confident of the
219 hospitalization and serious case counts in Wuhan after mid February, and in Guangzhou, where
220 excess capacities in diagnosis and treatment were reported based on both official and unofficial
221 sources. In addition, our projection of the ICU bed needs in US cities does not take into account
222 scenarios where local transmission may differ from that of Wuhan.

223 The contact rate in Wuhan during the early phase of the epidemic may have been much
224 higher than what we expect to occur in US cities because of the increased number of social
225 contacts that occurred in Wuhan due to the Lunar New Year celebrations. If social distancing
226 measures are effectively implemented early in US cities, the growth of the epidemic may be
227 delayed. But it is also possible that US cities may not be able to implement the extreme social
228 distancing measures that were put into place later in the epidemic in Wuhan. Therefore, the
229 actual number of hospital and ICU beds that will be needed over the course of a COVID-19
230 outbreak in a US city is impossible to estimate precisely. Our estimated capacity needs based
231 on a “Wuhan-like” outbreak could be a benchmark for what healthcare providers would expect
232 to see during the first three months of a local COVID-19 epidemic.

233 Historical evidence has shown that in 1918, US cities which imposed nonpharmaceutical
234 interventions early in the epidemic course and maintained their interventions over a long period
235 had lower peaks and fewer total cases of pandemic influenza than those which waited.^{16,17} Our
236 comparison of Wuhan and Guangzhou, although it is only two cities, dramatically illustrates the
237 same relationship of early intervention leading to lower epidemic sizes and peaks. The future
238 course of these epidemics and others around the world, of course, depends on the ability to
239 maintain burdensome control measures over an extended period.

240 In several countries with high-performing healthcare systems where SARS-CoV-2
241 transmission has been established earlier, both supplies of personal protective equipment in
242 hospitals and the availability of services has been problematic for COVID-19 care, and in all
243 locations, ICU bed capacity is limited.¹⁸ Plans are urgently needed to mitigate the effect of
244 COVID-19 outbreaks on the local healthcare system.

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321

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327

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332

333 **Figure legends:**

334

335 **Figure 1. Burden of serious COVID-19 disease in Wuhan and Guangzhou, China**

336 US data sources: US ICU beds;¹⁹ US empty ICU beds;²⁰ US inpatient beds;²³ US population
337 structure.²²

338

339 **Figure 2. Estimate number of critically ill patients at the peak of a Wuhan-like outbreak in**
340 **cities in the US, per 10,000 adults**

341 Top: taking into account of the proportion of population over 65 years of age

342 Bottom: taking into account of the proportion of population with hypertension

343 Wuhan: 2.6 per 10,000 adults were critically ill at the peak of the COVID-19 epidemic,

344 with a crude hypertension prevalence of 25.7% among adults (rate ratio for critical

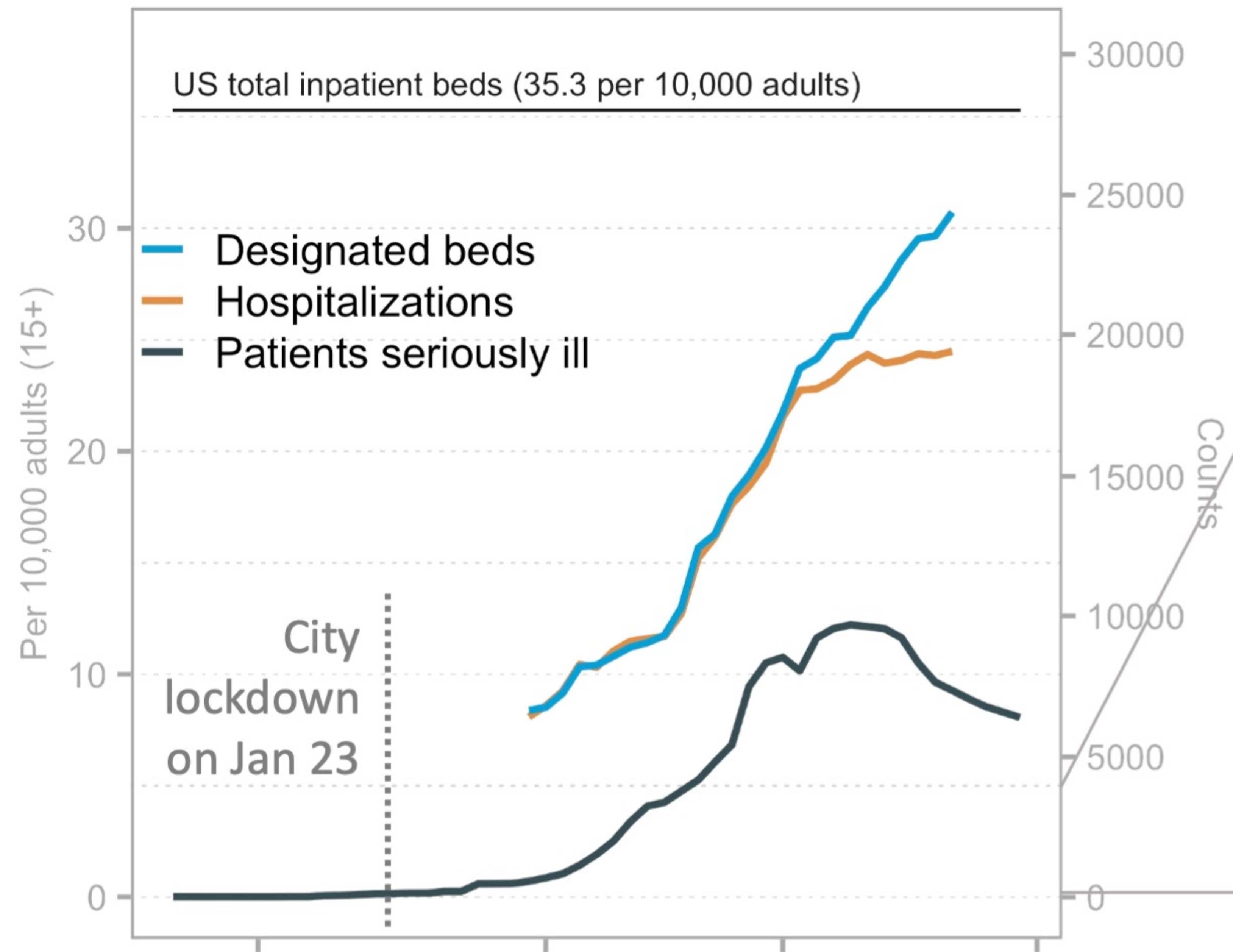
345 illness=6.9), and 15.9% adults over 64 years of age (rate ratio for critical illness=7.2).

346

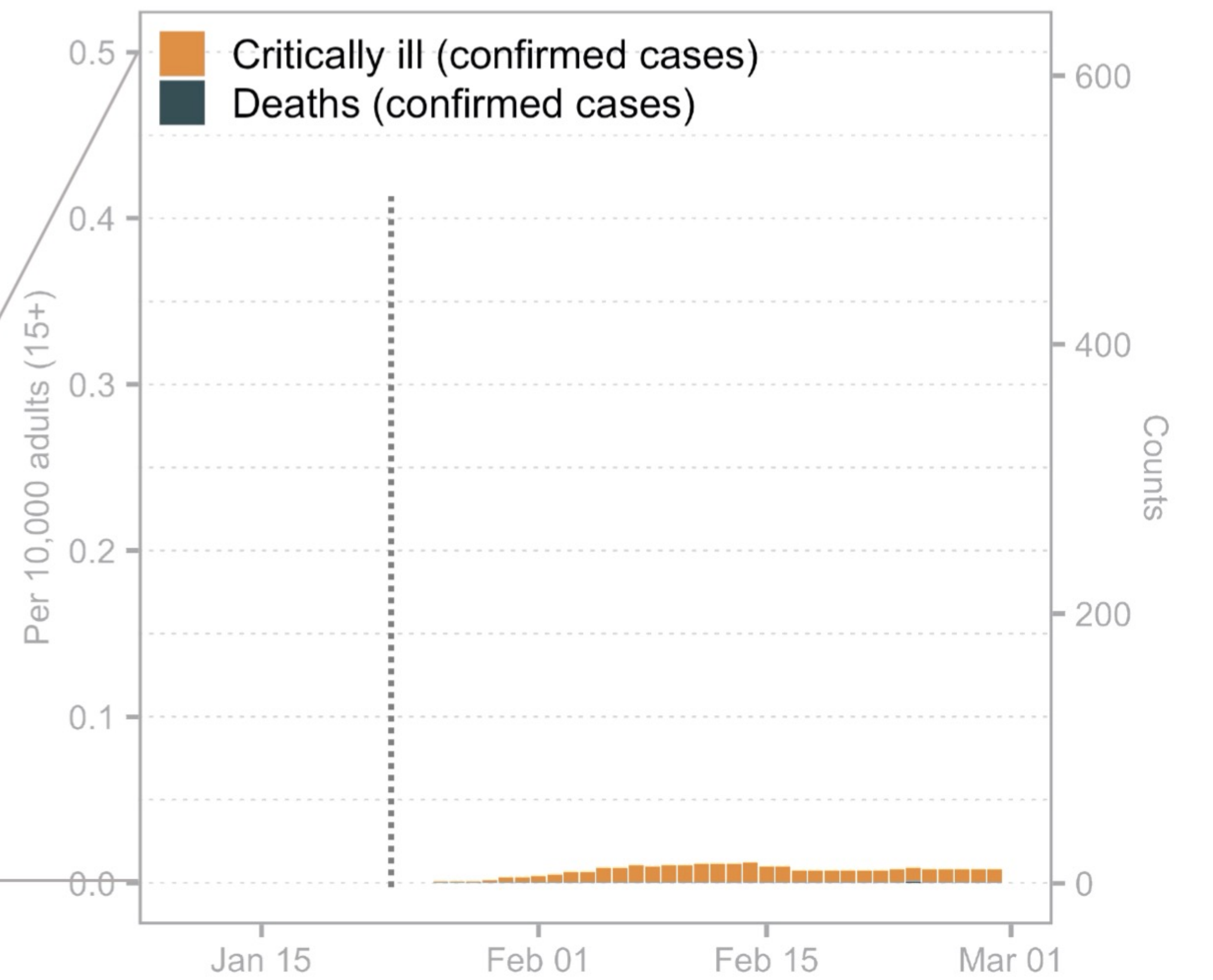
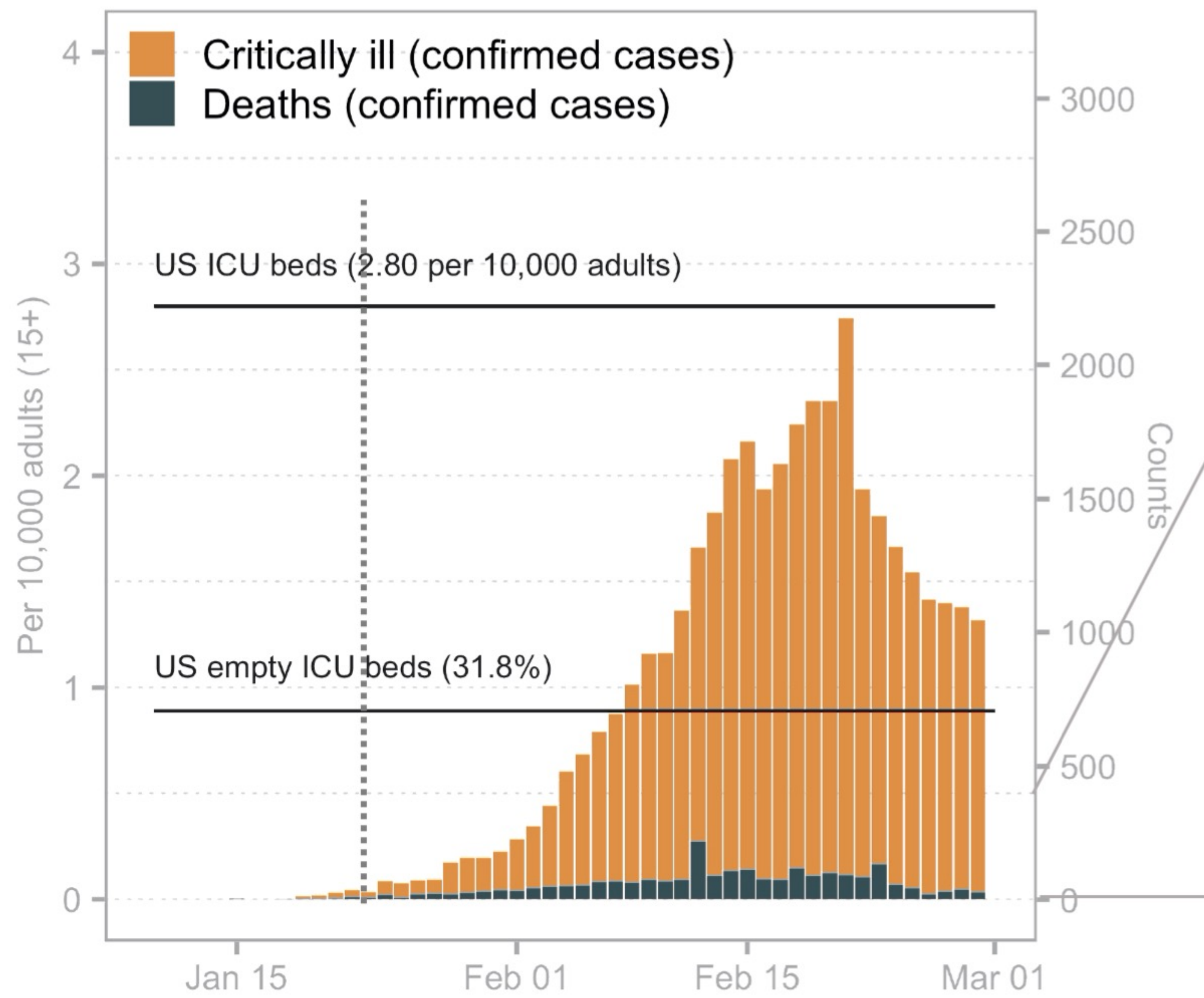
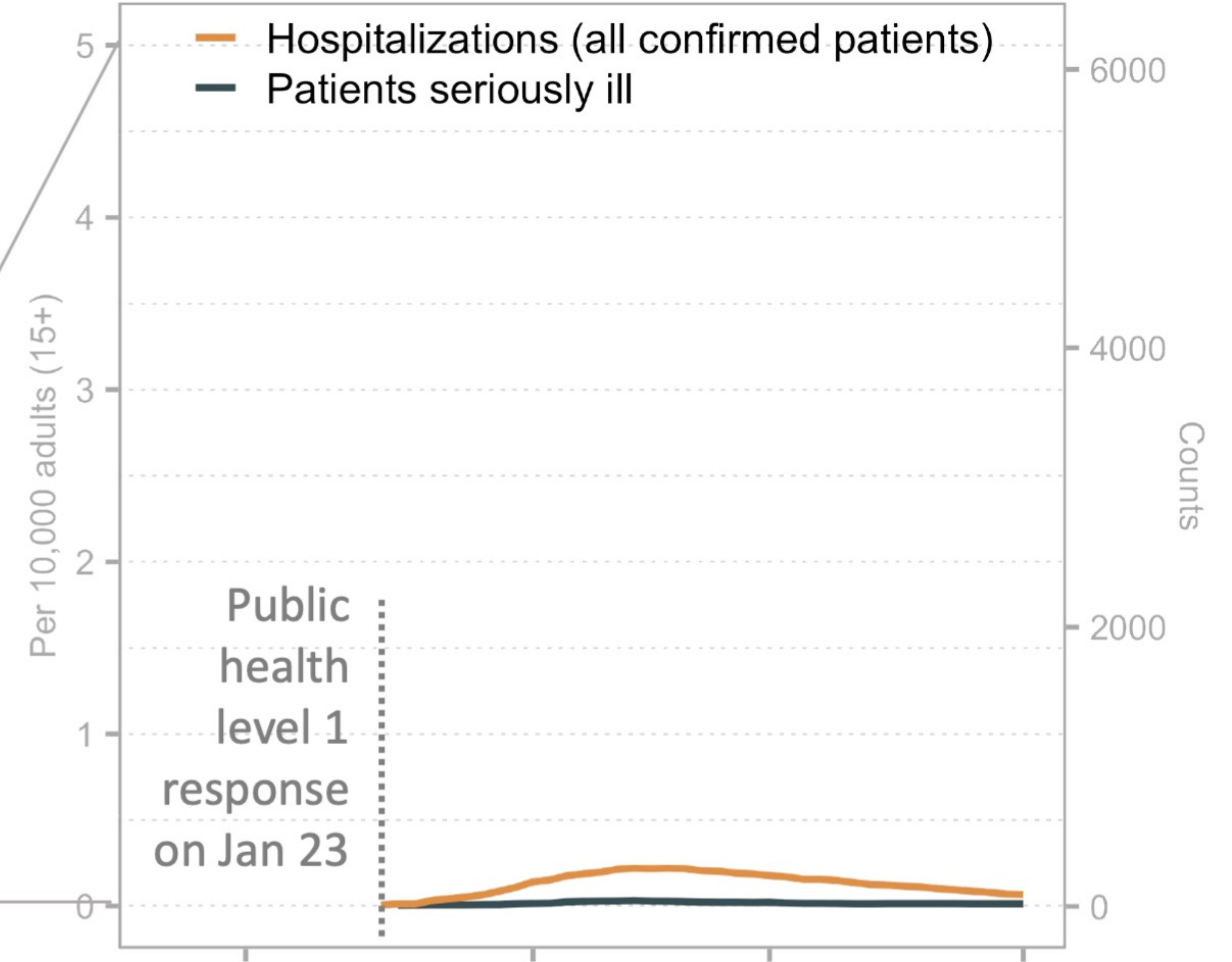
347

348

Wuhan



Guangzhou



Confirmed cases = 495
Deaths = 23

Confirmed cases = 7
Deaths = 0

