

Cremation Based Estimates Suggest Significant Under- and Delayed Reporting of COVID-19 Epidemic Data in Wuhan and China

Mai He (✉ Maihe@wustl.edu)

Washington University School of Medicine in St. Louis

Li Li

AT&T (United States)

Weisi Yan

Thomas Jefferson Medical College

Louis P. Dehner

Washington University School of Medicine in St. Louis

Lucia F. Dunn

The Ohio State University

Research Article

Keywords: COVID-19, cremation, cumulative infection, death, Wuhan, China

Posted Date: July 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-677438/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

1 **Cremation based estimates suggest significant under- and delayed reporting of COVID-19**
2 **epidemic data in Wuhan and China**

3 Mai He, M.D., Ph.D.,¹ Li Li, M.A.², Weisi Yan, M.D., Ph.D.,³ Louis P. Dehner, M.D.,¹ Lucia F.
4 Dunn, Ph.D.⁴

5

6 1. Department of Pathology and Immunology, Washington University School of Medicine
7 in St. Louis, St. Louis, MO 63110, USA

8 2. AT&T, Bedminster, NJ 07921, USA

9 3. Thomas Jefferson Medical College, Philadelphia, USA

10 4. Department of Economics, The Ohio State University, Columbus, OH 43210, USA

11

12 **Corresponding author:**

13 Mai He, M.D., Ph.D.

14 Department of Pathology and Immunology,

15 Washington University School of Medicine in St. Louis,

16 St. Louis, MO 63110, USA

17 Phone: (314) 273-1328

18 Email: Maihe@wustl.edu

19

20

21 **Abstract**

22 **Objective:**

23 China's COVID-19 statistics fall outside of recognized and accepted medical norms. Here we
24 estimated the incidence, death and starting time of the COVID-19 outbreak in Wuhan and China
25 based on cremation related information.

26 **Methods:**

27 Data sources included literature on COVID-19 in China, official Chinese government figures,
28 and media reports. A range of estimates is presented by an exponential growth rate model.

29 **Results:**

30 For the cumulative infections and total deaths, under different assumptions of case fatality rates
31 (from 2.5% to 10%) and doubling time 6.4 days, the estimates projected on February 7, 2020 in
32 Wuhan range from 305,000 to 1,272,000 for infections and from 6,811 to 7,223 for deaths - on
33 the order of at least 10 times the official figures (13,603 and 545). The implied starting time of
34 the outbreak is October 2019. The estimates of cumulative deaths, based on both funeral urns
35 distribution and continuous full capacity operation of cremation services up to March 23, 2020,
36 give results around 36,000, more than 10 times of the official death toll of 2,524.

37 **Conclusions:**

38 Our study indicates a potential significant under- and delayed reporting in Chinese official data
39 on the COVID-19 epidemic in Wuhan in early February, 2020.

40

41 **Keywords:** COVID-19; cremation; cumulative infection; death; Wuhan; China

42

43

44

45

46

47

48

49

50

51

52

53 **INTRODUCTION**

54 The spread of the coronavirus (COVID-19) has evolved into a global public health crisis
55 affecting all aspects of individual, societal and economic activity. On December 31, 2019, the
56 Wuhan City Health Commission announced that recent cases of pneumonia of unknown etiology
57 seen in some hospitals were related to the Wet Market and 27 cases were found by the time. This

58 official announcement conflicted with at least two official numbers and one media report which
59 were 45, 104 and 266 cases [1-3]. Reports from the official Chinese state-run media on February
60 2, 2020 showing large numbers of possible coronavirus victims who were not treated within the
61 medical establishment and hence may have fallen outside of government statistics, have led
62 many to believe there may be serious gaps in our understanding of the outbreak based on what
63 can be determined from this official government data [4].

64 As the epicenter of the COVID-19 initial outbreak, the epidemiological information from
65 Wuhan affects the response and preparation of other parts of China and rest of the world. It is
66 therefore important to attempt to accurately assess the actual number of cases and gain some
67 insights from this deduction to the time of the first cases.

68 The purpose of this report is to investigate the epidemiological information of the early
69 phase of the COVID-19 outbreak in Wuhan, after lockdown on January 23, 2019, based on
70 official Chinese government figures, published literature and media reports, focusing on
71 cremation related data. Our definition and estimate of COVID-19 related death is death that is
72 outside the normal range of cremation since cremation is the usual way of handling body in cities
73 in China. The estimates of incidence and deaths are higher by a magnitude of at least 10 times
74 the official figures. Our estimates are further supported by others who were also investigating the
75 situation and recent updates of funeral urn distribution in Wuhan. The potential impact of this
76 discrepancy is critical for both the medical projection of needs and for policy decisions relating
77 to public health.

78

79 **METHODS**

80 *Data Sources*

81 The official Chinese government figures include national and local Wuhan data [5] and
82 state-run media reports. Since there is no medical literature on “COVID-19, cremation” in
83 China, we searched on the internet for media reports in Chinese by “新型冠状病毒肺炎” (novel
84 coronavirus pneumonia) and “Wuhan” on the operation of crematory facilities in Wuhan as
85 widely reported by established news organizations both inside and outside of China [6-12].

86 *Cremation Data*

87 Daily cremation due to the COVID-19 outbreak is defined and estimated by total number
88 of estimated cremations in the time period of this study minus pre-outbreak average daily
89 cremations.

90 Detailed information on crematory facility and operation is listed in Appendix 1, but also
91 summarized in Table 1 [6,7]. Briefly, there are eight crematories in Wuhan, which under normal
92 circumstances would operate about 4 hours per day. Before the outbreak, cremation mainly
93 happened in the morning, according to Chinese rituals. Starting on or before January 25, 2020,
94 these were observed to be operating at or close to around-the-clock or 24 hours daily [6-12]. This
95 would put the current operating rate at about six times normal. Normal deaths per day can be

Table 1. Crematory Facilities and Operation in Wuhan, China

	Before lockdown on January 23, 2020	From January 25 to February 19, 2020	After February 19, 2020
Crematory facilities	86 cremation furnaces*	86 cremation furnaces*	86 cremation furnaces* 40 mobile crematory stations
Crematory operation	Four hours per day	24 hours per day	24 hours per day
Crematory capacity	Approximately 136 per day	816 per day (full capacity) 2,064 (maximum capacity) **	2,064 and 200 tons per day (5 tons “medical waste” including “animal bodies” per mobile crematory station, total capacity 5x40 = 200 tons)

97

98 * The furnace information is for seven funeral houses, Hankou, Wuchang, Qingshan, Caidian District, JiangXia Distric, Huangpi District, Xinzhou
99 District. Muslim Funeral House is not included in the table above, since the information there is scarce.

100 ** The maximum capacity is calculated for the seven funeral houses, assuming non-stop cremation, and simplified procedure, since no farewell
101 ceremony was allowed during lockdown period.

102

103

104

105

106 estimated as 136 based on an annual mortality rate of 0.00551 in a population of approximately 9
107 million (Wuhan government data) [13]. With the regular procedure, the additional 20 hours of
108 daily operation imply additional deaths of $5 (20/4) \times 136 = 680$ per day above normal, if the
109 services are utilized with full capacity. However, it was estimated that the maximal capacity of
110 cremation could be up to 2,100 bodies per day (see appendix 1).

111 This estimate was supported by media reports of support of additional crematory staff
112 from other cities and provinces being brought into Wuhan [14,15]. Since February 19, 40 mobile
113 crematory stations were also sent to Wuhan for the increasing need of cremation capacity
114 [16,17].

115 *Estimation*

116 We used an exponential model to estimate the cumulative infections and deaths in
117 Wuhan.

118 *Assumptions*

119 I. The median time of the incubation period for COVID-19 is 4.5 days from exposure to
120 symptom onset [18]. The median time from the symptom onset to death is 14 days [19].

121 Assuming it takes half a day from death to cremation, this implies that most of the deaths which
122 happened on and before February 11, 2020 were not impacted by any countermeasures in effect.

123 II. In this study, different assumptions of epidemic doubling time were applied. Wu et al.
124 statistically inferred case counts in Wuhan by internationally exported cases as of January 25 and
125 estimated doubling time as 6.4 days with 95% confidence interval (5.8, 7.1) [20]. Rodriguez et
126 al. analyzed Chinese official daily cumulative cases from January 20 to February 9, 2020, and

127 derived the doubling time for each province ranging from 1.42 to 3.05 days, with Hubei (where
128 Wuhan is located) as 2.54 with confidence interval (2.44, 2.64), based on an exponential model.
129 With no countermeasure in effect, we assumed doubling time was also 2.54 days before January
130 20 in this scenario [21].

131 III. Outcomes are either survival with probability $(1 - d)$ where d is the case fatality rate; or
132 death after 14 days with probability d .

133 IV. To extrapolate from the Wuhan cremation data to the total number of infected cases,
134 alternative assumptions of 2.5%, 5%, and 10% were utilized for the case fatality rate.

135 V. Though media reported that Wuhan cremation service operated around the clock since
136 January 25, 2020 [6-12], we assumed no full capacity was utilized until two weeks later, on
137 February 7, 2020. This assumption will be further discussed below.

138 *The Model*

139 Estimates of the total cases were calculated from an exponential growth model. At time
140 t , where t is the number of days since the occurrence of the initial case, the quantities of interest
141 are $N(t)$, the cumulative number of cases, $n(t)$, the daily cases, $D(t)$, the cumulative number of
142 deaths, $d(t)$, the daily deaths, and the case fatality rate d . $N(t) = c(e^{\lambda t} - 1) + 1$, so that $N(0) =$
143 1, where c is a constant and the parameter λ is set to match the reported doubling time. $n(t) \cong$
144 $(1 - e^{-\lambda}) N(t)$ and $D(t) \cong d e^{-14.5 \lambda} N(t)$. Matching the cumulative totals $N(t)$ to the model
145 where each existing case infects R_0 (the basic reproductive number) new cases on average after s
146 days (the serial interval) gives $c = R_0/(R_0 - 1)$. Wu et al. estimates 2.7 for R_0 [20]. Exponential
147 growth model was not applied for projections of $N(t)$ for Wuhan beyond the date February 7,

148 2020, due to the declining number of susceptible individuals and plausible effectiveness of city
149 lockdown.

150 The projections of $N(t)$ for Wuhan using doubling time 2.54 days approach half million
151 on 44th day, that the exponential growth model is unreliable. From the 45th day, we take into
152 account the declining number of susceptible individuals, and the model was modified (as in the
153 SIR simulation model) so that the relationship $n(t) = e^{\lambda}n(t - 1)$ becomes $n(t) =$

154 $e^{\lambda} \left(1 - \frac{N(t-1)}{P}\right)^{\frac{1}{s}} n(t - 1)$ where P is the population size of Wuhan after lock down.

155 The 95% confidence intervals presented in Table 2 are based on the confidence interval
156 for the doubling rate as presented. Confidence intervals for the estimated starting dates are not
157 provided because they depend on estimates of both λ and R_0 and also on the randomness in the
158 transmission of the infection in its very early stages.

159 RESULTS

160 Wuhan lockdown started on January 23, 2020. This study chose February 7 (two weeks
161 after the announcement of 24-hour-operation of cremation services), and February 12 (20 days
162 after lockdown) as the projected evaluation days. Retrospectively, February 12 was the day when
163 party leadership changes were undertaken in Wuhan and Hubei Province [22].

164 I. Chinese official data for Wuhan and China

165 The Chinese government's official COVID-19 cumulative confirmed diagnoses and
166 deaths data, from late January up to mid-February, and selected representative dates later, are
167 recorded in Table 2 for Wuhan and the whole of China [23]. Daily ratios of confirmed diagnosis

Table 2. Official COVID-19 Epidemic Data in Wuhan and China from January 23 to April 17, 2020

Date	Cumulative confirmed infections in Wuhan	Cumulative deaths in Wuhan	Fatality rate in Wuhan	Cumulative confirmed infections in China	Cumulative deaths in China	Fatality rate in China	Confirmed cases W/C	Deaths W/C
23-Jan (lockdown)	495							
25-Jan	618							
4-Feb	8351	362	4.33%	24324	490	2.01%	34.3%	73.9%
5-Feb	10117	417	4.12%	28018	563	2.01%	36.1%	74.1%
6-Feb	11618	478	4.11%	31161	636	2.04%	37.3%	75.2%
7-Feb	13603	545	4.01%	34546	722	2.09%	39.4%	75.5%
8-Feb	14982	608	4.00%	37198	811	2.18%	40.3%	75.0%
9-Feb	16902	681	4.03%	40171	908	2.26%	42.1%	75.0%
10-Feb	18454	748	4.05%	42638	1016	2.38%	43.3%	73.6%
11-Feb	19558	820	4.19%	44653	1113	2.49%	43.8%	73.7%
12-Feb	32994	1036	3.14%	59804	1367	2.29%	55.2%	75.8%
13-Feb	35991	1016	2.82%	63851	1380	2.16%	56.4%	73.6%
23-March	50006	2524	5.05%	81171	3277	4.04%	61.6%	77.0%
11-April	50008	2577	5.15%	82052	3339	4.07%	60.9%	77.2%
17-April	50,333	3,859	7.69%	82,692	4,632	5.60%	60.9%	83.3%

170 and death between Wuhan and China as whole were calculated and listed in Table 2. While the
171 increase was relatively stable throughout the early period shown, there was a marked addition of
172 confirmed cases on February 12, 2020, with 13,436 new cases reported in Wuhan and a total of
173 15,151 (including Wuhan's data) of new cases in all of China, amounting to cumulative
174 confirmed diagnoses of 32,994 cases in Wuhan and 59,804 cases in China as a whole, and 1,036
175 cases of cumulative deaths in Wuhan and 1,367 deaths in China. On February 12, 2020, Wuhan's
176 cases represented 55.2% and 75.8% of China's cases of cumulative confirmed diagnoses and
177 deaths, respectively. The case fatality rate due to COVID-19 ranged from 3 to 4% in Wuhan
178 during this period, and ultimately 5% by April 11, 2020 (Table 1).

179 On April 17, Wuhan City announced an adjustment of its death toll by additional 1,290,
180 and of confirmed diagnosis by 325 cases, making a total of confirmed diagnosis of 50,333 cases,
181 deaths of 3,869 cases, and crude case fatality rate of 7.69% [24,25].

182 II. Estimates of COVID-19 related deaths and cumulative infections in Wuhan

183 (a) *Simple linear calculation*

184 As a benchmark comparison, we have provided simple linear calculations with constant daily
185 deaths. We assume that cremation service did not reached 100% utilization until February 7, and
186 the utilization was 80% between January 25 to February 6, 2020. The results of these estimates
187 are listed in Table 3. Cumulative deaths are 9,384, for the nineteen days (January 25 to February
188 12, 2020) only. Based on the official crude case fatality rate of 3.14% (February 12, 2020, Table
189 1), the estimated cumulative infection was 298,854 within nineteen days (Table 3).

190
191

192

Table 3. Estimates of COVID-19 Outbreak in Wuhan, China for Feb 7 and Feb 12, 2020

Date	Methodology	Doubling Time	Daily Deaths	Cumulative Deaths	Fatality Rate	Daily Cases	Total Cases	Implied Starting Date
7-Feb	Exponential Model <i>95% confidence interval</i>	6.4 (5.8, 7.1)	680	6,946 (6,486, 7,529)	2.50% (assumed)	130,600 (111,900, 153,590)	1,272,400 (1,091,200, 1,363,500)	4-Oct-19
7-Feb	Exponential Model <i>95% confidence interval</i>	6.4 (5.8, 7.1)	680	7,223 (6,348, 7,596)	5.00% (assumed)	66,810 (55,650, 74,980)	650,900 (598,300, 665,700)	11-Oct-19
7-Feb	Exponential Model <i>95% confidence interval</i>	6.4 (5.8, 7.1)	680	6,811 (6,215, 7,663)	10.00% (assumed)	31,300 (28,100, 36,610)	305,000 (302,100, 325,000)	17-Oct-19
7-Feb	Exponential Model* <i>95% confidence interval</i>	2.54 (2.44, 2.64)	680	3,097 (2,812, 3,394)	3.14%	257,000 (241,000, 274,300)	2,230,500 (2,121,900, 2,375,000)	14-Dec-19
7-Feb	Chinese official	2.54**	67	545	3.14%	1,985	13,603	NA
12-Feb	Chinese official	NA	216	1,036	3.14%	13,436	32,994	NA
12-Feb	Linear Calculation**	NA	680	408 x 13+680 x 6 = 9,384	3.14%	21,656	298,854	NA

193

194 * From the 45th day, the model was modified so that $n(t) = e^{\lambda} \left(1 - \frac{N(t-1)}{P}\right)^{\frac{1}{S}} n(t-1)$, where P is the population after lock down.

195 ** The doubling time was derived by Rodriguez et al. using Chinese official data.

196 *** In the linear calculation methodology, we assumed constant daily death from Jan 25-Feb 12, and the total confirmed cases were
197 only calculated to reflect the accumulated cases within 19 days.

198

199

200

201 (b) *Exponential growth model*

202 Based on the cremation data inference that COVID-19 related deaths reached 680 on
203 February 7, 2020, estimation of infection on February 7 is calculated. With 6.4 day doubling rate
204 [20], and under assumption of the crude fatality rates of 2.5%, 5%, and 10%, cumulative
205 infections in Wuhan are 1,272,400, 650,900 and 305,000 respectively. Cumulative deaths are
206 6,946, 7,223 and 6,811 respectively. The implied start dates for the outbreak are October 4,
207 2019, October 11, 2019 and October 17, 2019, respectively.

208 Estimates based of a 2.54 day doubling rate are also presented with estimated confidence
209 intervals in Table 3. Since this doubling time was derived using Chinese official data, we
210 applied the official 3.14% fatality rate in the calculation. The total cases are projected to be 2.23
211 million with 95% confidence interval (2.12 million, 2.38 million) on February 7, 2020.

212 (c) *Estimates based on funeral urn distribution*

213 No one was allowed to pick up urns during the lockdown. Beginning on March 23,
214 Wuhan residents were allowed to collect crematory urns, with the target date as April 4 to
215 complete the distribution of the backlog. Estimates based urn collection are listed in Table 4.

216 III. Estimate of COVID related deaths and cumulative infections in all of China

217 If we use the Wuhan/China ratio based on China's official data listed in Table 1
218 (confirmed cases 39.4%), we can extrapolate estimates for China, with cumulative infections
219 potentially reaching 5.67 million on February 7, 2020.

220

221

Table 4. Estimate of COVID-19 Related Deaths in Wuhan, China up to March 23, 2020

Date	Methodology	Announced or Estimated Accumulated Death	Note	Announced or Implied Infections***
23-Mar	Chinese official announcement	2,524		50,006
23-Mar	Funeral Urn distribution*	35,708 = 45,500 - 9,792	45,500 = 7 x 500 x 13 (3/23 – 4/4) 9,792= 136 x 72 (1/23 – 4/4)	707,089
23-Mar	Assumed constant daily** death	36,720	80% cremation utilization from Jan 23 to Feb 6; 100% cremation utilization from Feb 7 to Mar 22	727,128

222

223 * This information only includes seven crematories. There are eight in Wuhan (see appendix 1).

224 ** This does not include potential cremations performed in the 40 mobile crematory stations set up in Wuhan after February 19, 2020.

225 *** Based on officially announced Wuhan fatality rate 5.05% on March 23, 2020

226

227

228

229

230 **DISCUSSION**

231 The escalating intervention leading to the unprecedented sudden lockdown of Wuhan and
232 the published medical literature by Chinese researchers and scientists suggest a discrepancy from
233 the officially announced figures of the outbreak. As the epicenter of the COVID-19 outbreak, the
234 necessary epidemiological information about Wuhan was not made available n for the world to
235 initiate plans for a response and to prepare for the potential crisis that is now upon us.

236 *Challenges for getting needed information in China*

237 A major challenge to an effective response existed in the lack of transparency in reporting
238 by China. With media reports providing fragmented information with no well-defined focus,
239 academic publications subject to selection bias, and possibly less than forthright government
240 data, many challenges have arisen in formulating a data driven approach to this world-wide
241 problem [26]. The current study used cremation-related information to estimate epidemiological
242 information including cumulative infections and deaths.

243 *Strength and limitations*

244 The strength of this approach is that cremation is a common data end point. We applied
245 an exponential growth model during a window period from lockdown until the intervention
246 started to show effects. Note that the approach of the simple exponential growth model is valid
247 under the assumption that countermeasures to slow the spread of the epidemic were ineffective
248 up to the date included. While people claimed that the lockdown in Wuhan combined with the
249 national emergency response have averted 96% of the cases by February 19, 2020 [27], it should
250 be considered that in the initial period after Wuhan lock down, the effectiveness of

251 countermeasures taken there could be impacted by many factors, including the lack of public
252 awareness, the cross infection at hospitals, the limitation of the medical capacity, the inadequacy
253 of the quarantine facility and space, and the family cluster chain-infections.. However, this is
254 beyond the scope of this manuscript.

255 A potential weakness of this study is that there is no cremation information in medical
256 literature. All cremation related information came from media reports. To reduce bias, we used
257 media reports from both within China and outside China [6-12]. We also compared our
258 cremation-based estimate to historical data. Since the time period of our study mainly fell into
259 the first quarter of 2020, we obtained the number of cremation during the first quarter of 2018
260 and 2019 from Wuhan government websites [28, 29] which are 14,833 and 14,700, respectively.
261 They are similar to each other and suggest a relatively consistent number of cremations in
262 normal years. Daily cremation could be calculated as approximately 163 to 165.

263 *Cumulative infections and deaths from cremation-based analysis*

264 Based on data from the seven of eight Wuhan crematories, our conservative estimates of
265 cumulative infections on February 7 are more than 10 times than those of the official data.

266 Chinese media raised concerns about infections and deaths beyond the official statistics;
267 for example, when the director of a fever clinic complained that he could admit only five out of
268 80 potentially infected patients, which suggested a potential 16-fold difference between possible
269 infected patients and confirmed diagnoses in Wuhan [4]. The report mentioned the limited
270 nucleic acid-based testing, which was available only after the sequencing data was announced on
271 January 11, 2020. This information also pointed to the limited and exhausted medical facility

272 capacity in Wuhan in late January and early February 2020. In Table 5, we list representative
273 medical facilities in Wuhan and additional support from rest of China. Note that Wuhan was
274 reported to have approximately 95,000 beds by the end of 2018 [30]. Wuhan designated 100,000
275 beds for COVID patients by February 20 [31]. This ratio of bed numbers to official confirmed
276 cumulative diagnoses 47,741 as of February 25, 2020 presents a discrepancy which cannot be
277 explained by other causes. Similarly, as of Mar 8, Wuhan had 178,900 health care professionals,
278 and 16,900 ventilators provided to Wuhan, to care for the officially recognized 50,000
279 (cumulative) patients by that time, is also inexplicable, unless most of the infected were admitted
280 to ICU around the same time [25].

281 *Comparison with other work*

282 Some researchers have inferred the percentage of undocumented infections, concluding
283 that approximately 86% of all infections were apparently undocumented and that these were the
284 source of infection for 79% of documented cases [32]. Scissors, examining out-migrants, has also
285 pointed out that China's COVID-19 figures are arithmetically impossible [33]. Tsang et. al.
286 estimated that by Feb 20, 2020, there would have been 232,000 (95% CrI (161,000-359,000))
287 confirmed cases in China as opposed to only 55,508 reported cases [34]. By using high-
288 resolution domestic travel and infection data, Sanche S et al projected the infected population
289 would be around 233,400 (95% CI 38,757–778,278) by the end of January [35].

290 Serological testing provides a powerful tool for retrospective study of infection rate and
291 infection. To and colleagues reported 17 positive serological testing results among 452 Hong
292 Kong residents returning from Hubei Province (Where Wuhan is part of it) [36], suggesting an
293 infection rate of 3.8%, estimating an infected population of 1.96 million in Hubei, 31 times more

294

Table 5. Medical Resources Available in Wuhan after Lockdown (January 23, 2020)

Item	Wuhan local existing¹	Local addition or Support from other places in China	Total	Official cumulative cases
Hospital beds	95,277 ²	Local goal for “bed reserve” 50,000 by Feb-10, 2020 80,000 by Feb-15,2020 100,000 by Feb-20,2020	By Feb-25,2020 including 24,387 ³ from Designated Hospitals, additional 86,000 bed reserve from remodeling	47,741 on Feb 25, 2020
Health care professional	136,300 (including 39,600 licensed doctors and 54,400 registered nurses)	42,600 from January 24 to March 8, 2020	178,900	49,948 on Mar 8, 2020
Ventilator	Not found	By March 3, 2020 16,900 delivered to Wuhan ⁴	Estimated as 20,000	49,540 on Mar 3, 2020

295 Note 1: Wuhan health resources has been increasing annually, the above statistics was based on the data at the end of 2018, from Wuhan Health
296 Commission 2018 Annual Report, published on May 28, 2020. http://wjw.wuhan.gov.cn/zwgk_28/tjsj/202005/P020200528783977258205.pdf,
297 last accessed on 6/12/2020.

298 Note 2: on Jan 22, 2020, seven hospitals were designated for COVID patients. By Feb 25, 2020, 55 hospitals became COVID designated.

299 Note 3: <http://www.bjnews.com.cn/inside/2020/03/09/701141.html> Last accessed on 6/11/2020

300 Note 4: http://www.gov.cn/fuwu/2020-03/04/content_5486929.htm. Last accessed on 6/11/2020, including 2,900 invasive ventilator and 140,000
301 non-invasive ventilators

302

303

304

305

306 than the official number. He and associates reported a 6.9% seropositivity in Wuhan population,
307 suggesting an infection of more than 1.3 million [37], far more than the Chinese official number
308 of around fifty thousand.

309 These studies raise similar concerns about the underreporting of Chinese COVID-19
310 cases and largely confirm our estimates based on cremation operation.

311 *Correlation our estimates with funeral urn distribution*

312 Since a major data source is the number of cremations in Wuhan, our estimates have been
313 further verified by the subsequent information of the funeral urn distribution. In late March,
314 *Newsweek* reported that roughly 5,000 urns were shipped to one of the eight Wuhan cremation
315 facilities. The number of urns that arrived in that one facility was already about twice of the
316 city's official overall death from COVID-19 toll [38]. Potential COVID-19 related death counts
317 from urn distribution for Wuhan could be 35,708 for seven funeral houses (Table 3). This is
318 consistent with our linear estimate of 36,720, based on the cremation service operation. Both
319 estimates are more than ten times of the official death toll (2,524 on March 23). Additionally,
320 neither took into account those potentially processed in the 40 mobile crematories which were
321 brought to Wuhan after February 19, 2020 for the newly constructed hospitals (Huoshen Shan
322 and Leishen Shan) and “Fangchang” hospitals [16,17]. The mobile crematory stations can each
323 process up to five tons of “medical waste” including “animal dead bodies” per day. Thus, the
324 calculations here could be significant under-estimates.

325

326

327 *Potential stating time for COVID-19 outbreak in Wuhan*

328 As reported by Huang C et al., symptom onset of the first confirmed case was December
329 1, 2019 [39]. Under the assumption of 6.4 doubling time, the start dates implied by this study
330 range from October 4, 2019 to October 17, 2019. The estimated “implied start dates” are
331 consistent with other reports where Kristian Andersen suggested a possible “start date” of
332 October 1, 2019 based viral genome analysis [40]. Under the assumption of 2.54 doubling time,
333 the implied start date is December 14, 2019. However, in this scenario the infection cases were
334 projected to total 2.23 million by February 7, 2020. If the doubling time 2.54 is close to the
335 truth, then China’s official data under reported by millions. If the doubling time 6.4 is close to
336 the truth, there was significant under- and delayed reporting of the COVID-19 epidemic
337 information by China in late January and early February, the critical time for the world to
338 respond and prepare for the pandemic. Given the serious implications of the COVID-19
339 pandemic, further investigations into this period in China needs to be carried out.

340

341 Readers are reminded of the assumptions that underlie our estimates, and they should
342 therefore be taken as approximate. However, even if there were non-negligible reporting errors
343 in these new data, the magnitude of the discrepancy between the results from their analysis and
344 China’s official figures suggests that the potential impact on the global efforts to control the
345 pandemic is obvious. Transparency in China is of critical importance for the world to learn from
346 this infection and for those in the future. While cremation is not a usually used data in medical
347 literature, at times of public crisis, and in situations of lacking transparency, any reasonable data

348 source should be utilized to have as accurate and early as possible of the pandemic so to take
349 timely action to stop the crisis as early as possible.

350

351 **Acknowledgements**

352 *Authors' contributions:*

353 He M: Study design, information search, data analysis and manuscript writing.

354 Li L: Study design, information search, data analysis and manuscript writing.

355 Dehner L: Manuscript writing.

356 Dunn L: Study design, data analysis and manuscript writing.

357 *Funding information:*

358 No Funding.

359 **Conflict of interests**

360 All authors declare no conflict of interest and have nothing to disclose.

361

362

363

364

365

366

367 **References**

- 368 1. Li Q, Guan X, Wu P, et al. Early Transmission Dynamics in Wuhan, China, of Novel
369 Coronavirus-Infected Pneumonia. *N Engl J Med.* 2020;382(13):1199-1207.
370 doi:10.1056/NEJMoa2001316.
- 371 2. Epidemiology Working Group for NCIP Epidemic Response, Chinese Center for Disease
372 Control and Prevention. The Epidemiological Characteristics of an Outbreak of 2019
373 Novel Coronavirus Diseases (COVID-19) in China. *Zhonghua Liu Xing Bing Xue Za*
374 *Zhi.* 2020 Feb 10;41(2):145-151. [Article in Chinese]
375 <https://pubmed.ncbi.nlm.nih.gov/32064853/>. PMID: 32064853
- 376 3. Ma J. Coronavirus: China's first confirmed Covid-19 case traced back to November 17.
377 [https://www.scmp.com/news/china/society/article/3074991/coronavirus-chinas-first-](https://www.scmp.com/news/china/society/article/3074991/coronavirus-chinas-first-confirmed-covid-19-case-traced-back)
378 [confirmed-covid-19-case-traced-back](https://www.scmp.com/news/china/society/article/3074991/coronavirus-chinas-first-confirmed-covid-19-case-traced-back) Last accessed on May 24, 2020.
- 379 4. 财经-统计数字之外的人：他们死于普通肺炎 [*People outside the statistics: Are they*
380 *dying from common pneumonia?*]. <https://chinadigitaltimes.net/chinese/2020/02/> Last
381 accessed February 12, 2020.
- 382 5. www.gov.cn.
- 383 6. Yi Cao. "Epidemics in New York worse than Wuhan??" April 4, 2020.
384 <http://blog.creaders.net/u/11405/202004/370363.html> Last accessed on May 25, 2020.

- 385 7. GM06. “Where do the bodies come from, that cannot be cremated even with all
386 crematory staff and burners running 24 hours?” February 10, 2020. [https://gnews.org/zh-](https://gnews.org/zh-hans/110207/)
387 [hans/110207/](https://gnews.org/zh-hans/110207/) Last accessed on May 25, 2020.
- 388 8. Jinxin Kandian. “I am at the first line of Wuhan funeral service, now needs some help”.
389 February 15, 2020.
390 https://k.sina.cn/article_7280195342_1b1eef70e02000pydh.html?from=society Last
391 accessed on May 25, 2020.
- 392 9. Hoonhout, T. Wuhan Residents Dismiss Official Coronavirus Death Toll: ‘The
393 Incinerators Have Been Working Around the Clock’ National Review.
394 [https://www.nationalreview.com/news/wuhan-residents-dismiss-official-coronavirus-](https://www.nationalreview.com/news/wuhan-residents-dismiss-official-coronavirus-death-toll-the-incinerators-have-been-working-around-the-clock/)
395 [death-toll-the-incinerators-have-been-working-around-the-clock/](https://www.nationalreview.com/news/wuhan-residents-dismiss-official-coronavirus-death-toll-the-incinerators-have-been-working-around-the-clock/) Last accessed April 6,
396 2020.
- 397 10. He C. Amid virus outbreak, funeral home officials in Wuhan reveal sharp increase in
398 cremations. [https://www.theepochtimes.com/exclusive-funeral-homes-in-coronavirus-](https://www.theepochtimes.com/exclusive-funeral-homes-in-coronavirus-ground-zero-cremating-dozens-of-bodies-a-day_3228938.html)
399 [ground-zero-cremating-dozens-of-bodies-a-day_3228938.html](https://www.theepochtimes.com/exclusive-funeral-homes-in-coronavirus-ground-zero-cremating-dozens-of-bodies-a-day_3228938.html) Last accessed February
400 12, 2020.
- 401 11. <https://www.chinatimes.com/cn/realtimenews/20200202001385-260409?chdtv> Last
402 accessed May 25, 2020.
- 403 12. “Wuhan funeral service under heavy pressure from the epidemic: Lockdown affects
404 processing time, body designated to crematory”. January 31, 2020.
405 <http://www.infzm.com/wap/#/content/175645> Last accessed on May 25, 2020.

- 406 13. Wuhan City Administration.
407 http://www.wh.gov.cn/2019_web/whyw/201910/t20191021_280212.html Last accessed
408 February 12, 2020.
- 409 14. “Marked increase during one night! 242 Deaths in Hubei + Funeral staff from all over
410 China hurried to go to support.” [http://news.migage.com/articles/一夜暴增！湖北242](http://news.migage.com/articles/一夜暴增！湖北242人亡+各地殡葬队急支援_3751982_yahootw.html)
411 [人亡+各地殡葬队急支援_3751982_yahootw.html](http://news.migage.com/articles/一夜暴增！湖北242人亡+各地殡葬队急支援_3751982_yahootw.html) Last accessed on May 25, 2020
- 412 15. “Wuhan pneumonia: Henan and Chongqing funeral teams going straight to support
413 Wuhan.” [https://www.chinapress.com.my/20200213/武汉肺炎-河南重庆-殡葬队-直](https://www.chinapress.com.my/20200213/武汉肺炎-河南重庆-殡葬队-直奔武汉施援手/)
414 [奔武汉施援手/](https://www.chinapress.com.my/20200213/武汉肺炎-河南重庆-殡葬队-直奔武汉施援手/) Last accessed on May 25, 2020.
- 415 16. http://www.moe.gov.cn/jyb_xwfb/xw_zt/moe_357/jyzt_2020n/2020_zt03/zydt/zydt_gxdt
416 [/zydt_gxkx_kjgg/202002/t20200219_422354.html](http://www.moe.gov.cn/jyb_xwfb/xw_zt/moe_357/jyzt_2020n/2020_zt03/zydt/zydt_gxdt/zydt_gxkx_kjgg/202002/t20200219_422354.html) Last accessed May 8, 2020
- 417 17. http://www.xinhuanet.com/politics/2020-02/21/c_1125606332.htm Last accessed May 8,
418 2020.
- 419 18. Interim Clinical Guidance for Management of Patients with Confirmed Coronavirus
420 Disease (COVID-19). [https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-](https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html#:~:text=The%20incubation%20period%20for%20COVID,CoV%2D2%20i)
421 [guidance-management-](https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html#:~:text=The%20incubation%20period%20for%20COVID,CoV%2D2%20i)
422 [patients.html#:~:text=The%20incubation%20period%20for%20COVID,CoV%2D2%20i](https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html#:~:text=The%20incubation%20period%20for%20COVID,CoV%2D2%20i)
423 [nfection.](https://www.cdc.gov/coronavirus/2019-ncov/hcp/clinical-guidance-management-patients.html#:~:text=The%20incubation%20period%20for%20COVID,CoV%2D2%20i) Last accessed on May 25, 2020.
- 424 19. Wang W, Tang J, Wei F. Updated understanding of the outbreak of 2019 novel
425 coronavirus (2019-nCoV) in Wuhan, China. *J Med Virol.* 2020;92(4):441-447.
426 doi:10.1002/jmv.25689.

- 427 20. Wu JT, Leung K, M Leung GM. Nowcasting and forecasting the potential domestic and
428 international spread of the 2019-nCoV outbreak originating in Wuhan, China: a
429 modelling study. *Lancet* 2020 Jan 31. PII: S0140-6736(20)30260-9. DOI:
430 10.1016/S0140-6736(20)30260-9.
- 431 21. Muniz-Rodriguez K, Chowell G, Cheung C-H, Jia D, Lai P-Y, Lee Y, et al. Doubling
432 time of the COVID-19 epidemic by province, China. *Emerg Infect Dis.* 2020 August
433 [Cited on May 25, 2020]. <http://dx.doi.org/10.3201/eid2608.200219>.
- 434 22. <https://time.com/5783401/covid19-hubei-cases-classification/> Last accessed May 8, 2020.
- 435 23. www.gov.cn.
- 436 24. <http://www.nhc.gov.cn/xcs/yqtb/202004/9d15772389c64d478713e710a756b883.shtml>
- 437 25. <http://m.china.caixin.com/m/2020-04-18/101544179.html>.
- 438 26. <https://chinadigitaltimes.net/chinese/2020/04/> 【立此存照】关于加强新冠肺炎科研论
439 文发表管理 Last accessed May 8, 2020.
- 440 27. Tian H, Liu Y, Li Y, et al. An investigation of transmission control measures during the
441 first 50 days of the COVID-19 epidemic in China. *Science.* 2020;368(6491):638-642.
442 doi:10.1126/science.abb6105.
- 443 28. Wuhan City 2018 First Quarter Statistics.
444 http://mzj.wuhan.gov.cn/zwgk_918/fdzdgg/tjxx/201806/t20180625_158420.shtml Last
445 accessed on March 26, 2021
- 446 29. Wuhan City 2019 First Quarter Statistics.
447 http://mzj.wuhan.gov.cn/zwgk_918/fdzdgg/tjxx/201905/t20190514_158438.shtml Last
448 accessed on March 26, 2021

- 449 30. <http://tongji.cnki.net/kns55/navi/YearBook.aspx?id=N2019010138&floor=1> Last
450 accessed on May 8, 2020.
- 451 31. <https://6do.news/article/2212649-61> Last accessed on May 8, 2020.
- 452 32. Li, R., Pei, S., Chen, B., Song, Y., Zhang, T., Yang, W., & Shaman, J. (2020). Substantial
453 undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-
454 CoV2). *Science*. doi: 10.1126/science.abb3221.
- 455 33. Scissors D. Estimating the true number of China's COVID-19 cases. American
456 Enterprise Institute. [https://www.aei.org/research-products/report/estimating-the-true-
457 number-of-chinas-covid-19-cases/](https://www.aei.org/research-products/report/estimating-the-true-number-of-chinas-covid-19-cases/) Last accessed April 22, 2020.
- 458 34. Tsang TK, Wu P, Lin Y, et al. Effect of changing case definitions for COVID-19 on the
459 epidemic curve and transmission parameters in mainland China: a modelling study.
460 *Lancet Public Health*. 2020 Apr 21. pii: S2468-2667(20)30089-X. doi: 10.1016/S2468-
461 2667(20)30089-X.
- 462 35. Sanche S, Lin YT, Xu C, Romero-Severson E, Hengartner N, Ke R. High contagiousness
463 and rapid spread of severe acute respiratory syndrome coronavirus 2. *Emerg Infect Dis*.
464 2020 Jul [cited on June 3, 2020]. <https://doi.org/10.3201/eid2607.200282> DOI:
465 10.3201/eid2607.200282
- 466 36. To KK, Cheng VC, Cai JP, Chan KH, Chen LL, Wong LH, et al. Seroprevalence of
467 SARS-CoV-2 in Hong Kong and in residents evacuated from Hubei province, China: a
468 multicohort study. *Lancet Microbe*. 2020 Jul;1(3):e111-e118. doi: 10.1016/S2666-
469 5247(20)30053-7.

- 470 37. He Z, Ren L, Yang J, Guo L, Feng L, Ma C, et al. Seroprevalence and humoral immune
471 durability of anti-SARS-CoV-2 antibodies in Wuhan, China: a longitudinal, population-
472 level, cross-sectional study. *Lancet*. 2021 Mar 20;397(10279):1075-1084. doi:
473 10.1016/S0140-6736(21)00238-5.
- 474 38. Newsweek. March 29, 2020. [https://www.newsweek.com/wuhan-covid-19-death-toll-
475 may-tens-thousands-data-cremations-shipments-urns-suggest-1494914](https://www.newsweek.com/wuhan-covid-19-death-toll-may-tens-thousands-data-cremations-shipments-urns-suggest-1494914).
- 476 39. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel
477 coronavirus in Wuhan, China. *Lancet* 2020 Jan 15. DOI:[https://doi.org/10.1016/S0140-
478 6736\(20\)30183-5](https://doi.org/10.1016/S0140-6736(20)30183-5)
- 479 40. Cohen J. Wuhan seafood market may not be source of novel virus spreading globally.
480 [https://www.sciencemag.org/news/2020/01/wuhan-seafood-market-may-not-be-source-
481 novel-virus-spreading-globally](https://www.sciencemag.org/news/2020/01/wuhan-seafood-market-may-not-be-source-novel-virus-spreading-globally) Last accessed February 18, 2020.

482

483

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [CremationAppendix1.docx](#)