Original Article

Estimated Use of Intensive Care Beds Due to COVID-19 in Germany Over Time

Andreas Stang, Maximilian Stang, Karl-Heinz Jöckel

Summary

Background: There is concern in Germany that the capacity of intensive care unit (ICU) beds may not be sufficient for the COVID-19 pandemic. The aim was to determine the maximum daily number of COVID-19 cases requiring intensive care from 11 April through 30 June 2020.

Methods: We assumed three non-exponential scenarios for the development of the cumulative case numbers up to 30 June 2020 (linear, slow quadratic, and fast quadratic). We assumed that 3–10% of of patients would require intensive care, that 8 days would elapse from a positive test to the need for intensive care, and that intensive care would be necessary for 14 or 20 days.

Results: Extrapolation of the maximum registered daily COVID-19 cases reveals a range of 4133 to 12 233 cases. Assuming that 3–10% of newly detected COVID-19 cases become intensive care patients and the average length of ICU stay is between 14 and 20 days, we arrive at a maximum daily number of ICU cases between 1989 (linear extrapolation, 3% ICU, 14 days in ICU) and 20 966 (fast quadratic extrapolation, 10% ICU, 20 days in ICU).

Discussion: Our results give no rise for concern that triage of COVID-19 patients may become necessary in Germany. However, the occupancy of ICU beds should be managed centrally to ensure optimal use of bed capacity. If, contrary to expectations, an exponential increase in case numbers should occur after all, our results will become invalid.

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In the context of the current development of the SARS-CoV-2 pandemic in Germany, there is concern that the number of intensive care unit (ICU) beds in hospitals will not suffice for the COVID-19 case volume. Television companies have been broadcasting triage scenarios from Italy in which doctors have to decide which patients will be ventilated and which not. There is fear that when the pandemic reaches its peak in Germany, a similar triage situation will arise. Press headlines such as "RKI: not enough intensive care beds" [1] lead to anxiety and uncertainty in the population.

According to the intensive care registry maintained by the German Interdisciplinary Association for Intensive Care and Emergency Medicine (*Deutsche Interdisciplinäre Vereinigung für Intensiv- und Notfallmedizin*, DIVI), as of 9 April 2020 there were 16 734 intensive care beds at the 680 hospital sites that had supplied data to the registry, of which 9695 (58%) were occupied and 7038 (42%) were free. On the same day there were 1888 COVID-19 patients in ICUs, of whom 1464 (78%) were being ventilated [2]. The DIVI data from 17 April 2020 show a total of 2601 COVID-19 patients being treated in ICUs, with 73.7% receiving oxygenation or artificial ventilation [3].

The aim of this study was to determine the maximum numbers of COVID-19 cases requiring intensive care in the period 11 April to 30 June 2020 with different non-exponential extrapolations of the development in reported COVID-19 cases over time.

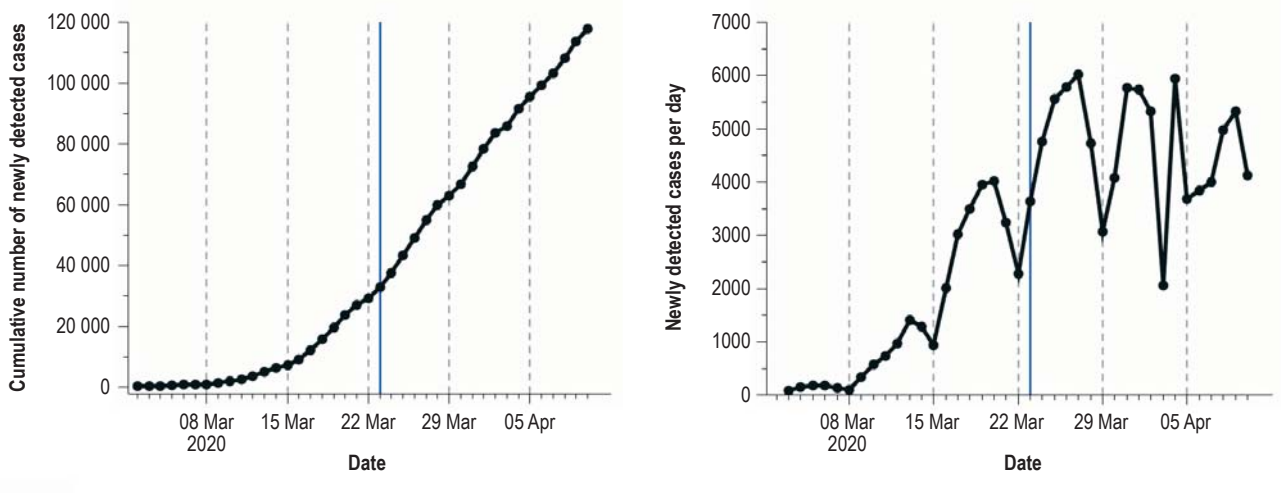
Material and methods

We extracted the cumulative number of laboratory-confirmed COVID-19 infections in Germany for the period 2 March 2020 to 10 April 2020 (4). Using the daily cumulative case numbers, we calculated the daily number of newly detected COVID-19 cases.

For the period 11 April to 30 June 2020, we assumed three different scenarios for the development of the cumulative case numbers, based on the cumulative number of 117 658 cases detected by 10 April 2020 and the 4133 new cases detected on 10 April 2020:

- Linear growth of the cumulative case numbers
- A slow quadratic increase in cumulative case numbers
- A fast quadratic increase in cumulative case numbers

FIGURE 1



Observed cumulative and daily numbers of newly confirmed COVID-19 cases up to 10 April 2020 (data from Robert Koch Institute [4])
Vertical blue line: start of lockdown on 23 March 2020; vertical dotted lines: Sundays

The quadratic extrapolation follows the formula $f = a \times i^2 + (b + a) \times i + 117\,658$, with f being the extrapolated cumulative number of COVID-19 cases, a being a quadratic component of the slope, b being the daily number of new cases (e.g., 4133), i being the rescaled calendar date with the first calendar date rescaled to 1, and 117 658 being the cumulative number of COVID-19 cases before extrapolation. We used values of 0 (linear extrapolation), 25 (slow quadratic extrapolation), and 50 (fast quadratic extrapolation) for a. Since the number of daily reported new COVID-19 cases did not continue increasing after 27 March 2020, we did not include exponential growth of cumulative case numbers.

Using the extrapolated daily cumulative case numbers, we estimated the daily number of newly detected COVID-19 cases. Subsequently, we assumed different proportions of new patients needing intensive care (3–10%), based on the experience in Spain (6.2%) [5], Italy (9–11%) [6], and the USA (8.2%) [7]. Based on the calibration study (see below) for the German data, we assumed a proportion of 3%.

In addition, we assumed an average period of 8 days from detection of COVID-19 to the need for intensive care. We assumed the duration of intensive care to be either 14 or 20 days. The estimated number of daily ICU cases up to 18 April is based on the daily numbers of new COVID-19 infections reported by the Robert Koch Institute (RKI) up to 10 April 2020. The assumed interval of 8 days between reporting and the requirement for intensive care explains why the daily ICU cases until 18 April could be estimated from empirical data. Thereafter, the estimated numbers are based on the extrapolated new COVID-19 case numbers as yielded by the three scenarios mentioned above for the period 11 April through 30 June 2020.

The number of COVID-19 patients requiring oxygenation or ventilation in the ICU can be calculated by multiplying our case numbers for COVID-19 patients needing ICU treatment by 73.7%, which corresponds to the proportion of COVID-19 patients in the ICU requiring oxygenation or ventilation.

The DIVI intensive care registry reported for 9 April 2020 that 1888 COVID-19 cases were being treated in German ICUs [2]. We used this number to determine the calibration of our projection of COVID-19 patients requiring daily intensive care. All calculations were performed with SAS 9.4 (Cary, NC, USA).

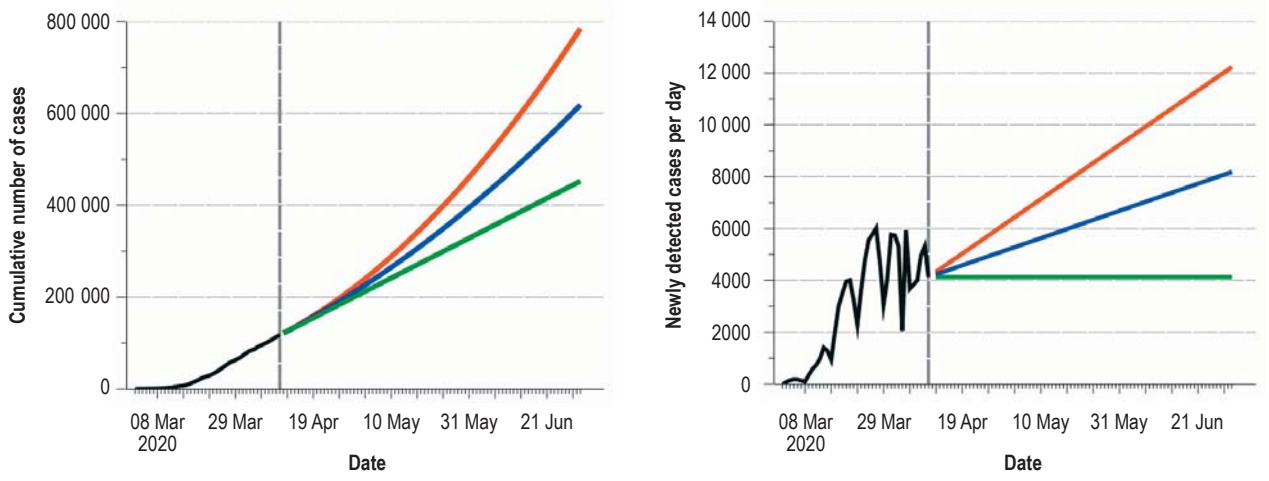
Results

Since the nationwide measures to reduce interpersonal contact (lockdown) from 23 March to 10 April 2020 there has been an almost linear increase in the cumulative number of confirmed COVID-19 cases in Germany. The daily number of confirmed new cases has not shown any pronounced increase since the lockdown; it has fluctuated between 2051 and 6014 cases with a median of 4757 cases. The lower numbers of new cases reported on Sundays arise from the fact that not all health authorities report new cases to the Robert Koch Institute on Sundays and therefore represent an artifact *(Figure 1)*.

The extrapolation of newly registered COVID-19 cases yields a maximum of 4133 (linear extrapolation) to 12 233 cases (fast quadratic extrapolation) per day up to 30 June 2020, with a total number of between 452 431 (linear extrapolation) and 784 531 (fast quadratic extrapolation) newly registered COVID-19 cases by that date *(Figure 2)*.

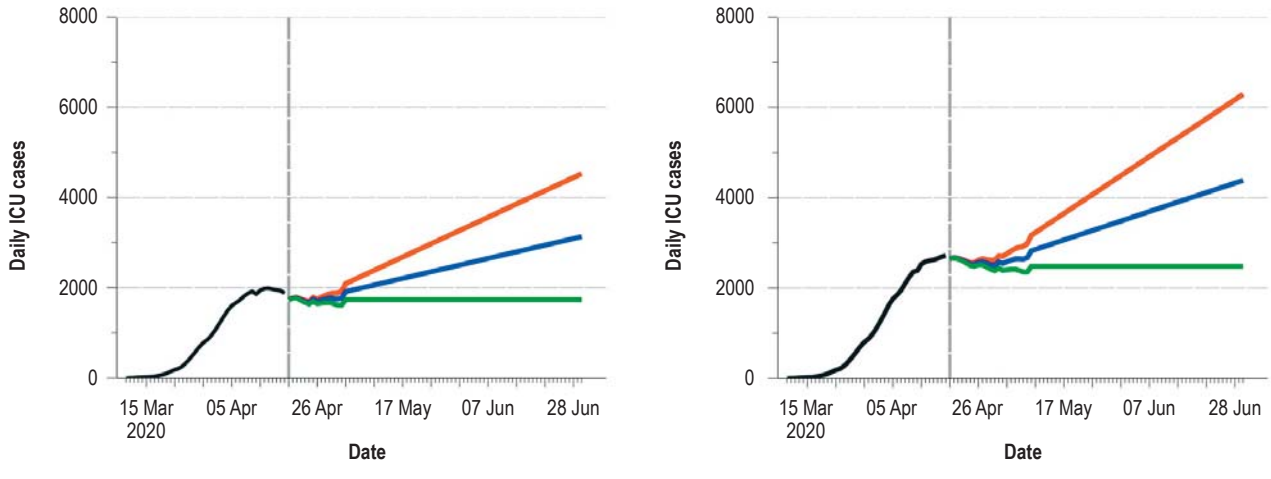
If a linear temporal trend of cumulative case numbers continues and 3% of the patients with

FIGURE 2



Observed (up to 10 April 2020) and extrapolated cumulative and daily numbers of newly confirmed COVID-19 cases
Green line: linear extrapolation of the cumulative number of newly confirmed COVID-19 cases
Blue line: slow quadratic extrapolation of the cumulative number of newly confirmed COVID-19 cases
Red line: fast quadratic extrapolation of the cumulative number of newly confirmed COVID-19 cases
Vertical dashed line: after this line the daily numbers are based on the extrapolated number of newly diagnosed COVID-19 cases.

FIGURE 3



Estimated daily numbers of patients with COVID-19 requiring ICU treatment
Left: the proportion requiring 14 days of ICU treatment, starting on average 8 days after diagnosis (3%)
Right: the proportion requiring 20 days of ICU treatment, starting on average 8 days after diagnosis (3%)
Green line: linear extrapolation of the cumulative number of newly confirmed COVID-19 cases
Blue line: slow quadratic extrapolation of the cumulative number of newly confirmed COVID-19 cases
Red line: fast quadratic extrapolation of the cumulative number of newly confirmed COVID-19 cases
Vertical dashed line: to the right of this line (19 April 2020) the estimated daily ICU cases are based on extrapolated numbers of daily registered COVID-19 cases.

TABLE 1

Estimation of the daily number of COVID-19 cases requiring treatment in an intensive care unit (ICU) in Germany from 11 April to 30 June 2020 (assuming 8 days from report to need for intensive care)*

Trend	Need for ICU care (%)	Maximum number of COVID-19 cases needing ICU care	Date
Linear Average ICU stay 14 days	3 4 5 6 7 8 9 10	1989 2652 3315 3978 4641 5304 5967 6630	14 April
Average ICU stay 20 days	3 4 5 6 7 8 9 10	2790 3720 4650 5580 6510 7440 8370 9300	20 April
Slow quadratic Average ICU stay 14 days	3 4 5 6 7 8 9 10	3132 4176 5221 6265 7309 8353 9397 10 441	30 June
Average ICU stay 20 days	3 4 5 6 7 8 9 10	4385 5846 7308 8770 10 231 11 693 13 154 14 616	
Fast quadratic Average ICU stay 14 days	3 4 5 6 7 8 9 10	4529 6038 7548 9058 10 567 12 077 13 587 15 096	30 June
Average ICU stay 20 days	3 4 5 6 7 8 9 10	6290 8386 10 483 12 580 14 676 16 773 18 869 20 966	

* Maximum daily COVID-19 cases within the time interval; if the maximum extends over a longer period, the first date of occurrence of the maximum is presented

COVID-19 come to need intensive care, the maximum daily ICU bed occupancy is reached around the middle of April (14 April for 14 days of intensive care, 20 April for 20 days of intensive care). The maximum number of patients requiring intensive care at the same time would be 1989 (14 days' intensive care) or 2790 (20 days' intensive care). With a fast quadratic increase in cumulative case numbers, the maximum utilization would be reached on 30 June 2020, with 4529 (14 days of intensive care) or 6290 patients (20 days of intensive care) *(Figure 3, Table 1)*. The proportion of ICU patients requiring oxygenation or artificial ventilation is expected to be 73.7%. For example, if 6290 patients require intensive care on 30 June 2020, 4636 of them can be expected to need oxygenation or artificial ventilation.

Under the assumption of a constant daily number of reported new cases of COVID-19, the proportion of all ICU beds in Germany that is needed each day for COVID-19 patients depends heavily on the other assumptions made. Assuming 20 000 new cases daily (around five times as many cases as observed on 10 April 2020) and 6% of patients requiring intensive care for 14 days, 16 800 ICU beds would be needed, i.e., 56% of the current capacity *(Table 2)*.

With 3.0% of patients needing intensive care, an interval of 8 days between the reporting of a positive test and intensive care becoming mandatory, and a 14-day stay in intensive care, our projection for 9 April 2020 yields 1879 patients requiring intensive care, while the DIVI registry reported 1888 patients with COVID-19 being treated in ICUs on that day. However, the DIVI intensive care registry was not at that time receiving data for all ICU beds in Germany. The registry covered about 83% of all hospitals, particularly the larger hospitals and university clinics. We speculate that circa 90% of the COVID-19 cases requiring intensive care at that time were included in the registry. That would imply a complete total of around 2098 patients. With 3.3% of patients needing intensive care, an interval of 8 days between the reporting of a positive test and intensive care becoming mandatory, and a 14-day stay in intensive care, our projection amounts to 2066 patients.

Discussion

We used three pessimistic non-exponential scenarios of the development of numbers of newly diagnosed COVID-19 cases in Germany, despite the fact that the number of newly detected COVID-19 cases has not been increasing, but rather stagnating, since the end of March 2020. Under the assumptions that 3–10% of newly detected COVID-19 patients require intensive care and their average length of ICU stay is either 14 or 20 days, we arrive at maximum daily case numbers in ICUs between 1989 (linear extrapolation, 3% ICU, 14 days in the ICU) and 20 966 (fast quadratic extrapolation, 10% ICU, 20 days in the ICU). Calibration with the COVID-19 ICU occupancy figures numbers from the DIVI registry for 9 April 2020 indicates a maximum

TABLE 2

Number of intensive care unit (ICU) beds needed per day in relation to the daily number of new COVID-19 cases, the proportion of patients requiring intensive care, and the length of ICU stay

Daily number of new cases	Need for intensive care (%)	Length of ICU stay	ICU beds needed per day	Proportion of overall ICU bed capacity in Germany (%)	Length of ICU stay	ICU beds needed per day	Proportion of overall ICU bed capacity in Germany (%)
4133	3	14 days	1736	6	20 days	2480	8
8000			3360	11		4800	16
12 000			5040	17		7200	24
16 000			6720	22		9600	32
20 000			8400	28		12 000	40
40 000			16 800	56		24 000	80
4133	4	14 days	2314	8	20 days	3306	11
8000			4480	15		6400	21
12 000			6720	22		9600	32
16 000			8960	30		12 800	43
20 000			11 200	37		16 000	53
40 000			22 400	75		32 000	107
4133	5	14 days	2893	10	20 days	4133	14
8000			5600	19		8000	27
12 000			8400	28		12 000	40
16 000			11 200	37		16 000	53
20 000			14 000	47		20 000	67
40 000			28 000	93		40 000	133
4133	6	14 days	3472	12	20 days	4960	17
8000			6720	22		9600	32
12 000			10 080	34		14 400	48
16 000			13 440	45		19 200	64
20 000			16 800	56		24 000	80
40 000			33 600	112		48 000	160
4133	7	14 days	4050	13	20 days	5786	19
8000			7840	26		11 200	37
12 000			11 760	39		16 800	56
16 000			15 680	52		22 400	75
20 000			19 600	65		28 000	93
40 000			39 200	131		56 000	187
4133	8	14 days	4629	15	20 days	6613	22
8000			8960	30		12 800	43
12 000			13 440	45		19 200	64
16 000			17 920	60		25 600	85
20 000			22 400	75		32 000	107
40 000			44 800	149		64 000	213
4133	9	14 days	5208	17	20 days	7439	25
8000			10 080	34		14 400	48
12 000			15 120	50		21 600	72
16 000			20 160	67		28 800	96
20 000			25 200	84		36 000	120
40 000			50 400	168		72 000	240
4133	10	14 days	5786	19	20 days	8266	28
8000			11 200	37		16 000	53
12 000			16 800	56		24 000	80
16 000			22 400	75		32 000	107
20 000			28 000	93		40 000	133
40 000			56 000	187		80 000	267

* Newly reported COVID-19 case as of 10 April 2020: n=4.133; all calculations assume that the daily number of newly reported cases remains constant over time; the total ICU bed capacity in Germany is assumed to be n=30 005 beds.

Key Messages

- Provided there is no exponential increase in COVID-19 cases numbers in Germany, the country's existing intensive care bed capacity seems sufficient.
- In view of the course the COVID-19 pandemic is taking in Germany, there appears to be no need for a debate about triage; intensive care bed occupancy should be coordinated on a nationwide basis, however, particularly at times of high case numbers.
- If 16 000 new cases of COVID-19 were detected daily, 6% of the patients needed intensive care, and all of these stayed in the intensive care unit for 20 days, 19 200 intensive care beds (64% of all such beds in Germany) would be needed each day for patients with COVID-19.

daily number of COVID-19 patients requiring intensive care that is closer to the low than to the high end of this range.

From our point of view, the results of the extrapolation give no rise for concern about an impending necessity for triage of COVID-19 patients requiring intensive care. It should be noted, however, that not all ICU beds are available for COVID-19 cases. On 17 April 2020, for example, 51% of the ICU beds were occupied by patients other than those with COVID-19. Furthermore, the occupancy of ICU beds in hospitals in Germany is not uniform, so in the absence of nationwide coordination the ICUs of some hospitals may be overloaded while others have low occupancy.

In contrast to our non-exponential extrapolations, Meares and Jones used an exponential extrapolation of the COVID-19 case numbers in Australia to estimate the required ICU capacity [8]. We chose not to use this approach, because since 27 March 2020, numbers of newly reported COVID-19 cases in Germany have stagnated or declined. Furthermore, a gradual, controlled loosening of the lockdown with continued compliance with hygiene measures and an anticipated rapid response in the event of an increase in the number of new COVID-19 cases makes a future exponential increase in the number of new cases in Germany unlikely. Although it does not at the moment seem very likely that exponential growth will resume for an extended period of time, policies are needed to ensure that this will not happen. It should be noted that our results do not contain any recommendations for action to ease the lockdown.

There are several factors that limit our results. First, we could only use laboratory-confirmed COVID-19 cases from the period 2 March through 20 April 2020 for our estimation. Due to the limited availability of COVID-19 test kits and therefore restricted use of this test, and due to its limited sensitivity, the true number of COVID-19 cases in Germany will be considerably larger than officially reported by the Robert Koch Institute. Li et al. recently estimated that 86% of all COVID-19 infections in China went undocumented [9]. Second, the development of the cumulative number of newly registered COVID-19 cases up to the end of June 2020 is a projection. However, we used three different pessimistic non-exponential scenarios of the development in Germany despite the fact that the daily number of newly reported COVID-19 cases has not been increasing, but rather stagnating, since the end of March 2020. Third, we could not distinguish between COVID-19 patients requiring intensive care with or without artificial ventilation. Our estimated case numbers for COVID-19 cases requiring intensive care can be used to estimate the numbers of patients requiring non-invasive ventilation, mechanical ventilation, high-flow oxygen therapy, or extracorporeal membrane oxygenation on the basis of our assumption, from DIVI intensive care registry data, that 73.7% of COVID-19 patients admitted to German ICUs need one or other of these treatments.

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Conflict of interest statement

The authors declare that no conflict of interest exists.

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