Title: Modelling the impact of COVID-19 upon intensive care services in New South Wales

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The known:
COVID-19 has been diagnosed in over 1,000 Australians, with the notification rate being the highest in NSW.

The new:
This study applies two statistical models to demonstrate the effect of COVID-19 upon critical care services. Even with limited mitigation, the effect is expected to overwhelm existing ICU capacity.

The implications:
Urgent action is required to reduce transmission of COVID-19, and increase the capacity of critical care services.

Abstract

Background: The Australian healthcare system faces a mounting burden due to COVID-19. Modelling performed in a comparable population in the United Kingdom anticipates a substantial burden for intensive care departments.

Methods: This analysis uses two approaches to estimating intensive care unit (ICU) bed demands associated with COVID-19 in the context of local health districts in NSW. In the first approach, the findings of an individual-based simulation model undertaken in the United Kingdom (UK) was applied to the age distribution of the NSW population. In the second approach, we developed a compartmental model applied to the NSW population. In both models, we estimated the number of hospitalisations and peak ICU demand at the initial peak of the COVID-19 epidemic, under a number of mitigation strategies.

Results: Applying UK-based model to the NSW population, the peak demand for ICU beds was forecast to be 6,965 ICU beds with an intensive mitigation strategy (797% of the ICU capacity prior to COVID-19). The compartmental model estimated that under a strategy that reduced transmission by one third, at least 5,109 ICU beds would be required (584% of the prior ICU capacity).

Conclusions: The burden upon intensive care services due to COVID-19 was forecast to be immense with both modelling approaches. Strategies to mitigate transmission must be accompanied by substantial increases in the capacity of critical care services in advance of peak demand. Modelling is an important tool to assist policymakers and the public to understand the impacts pandemic diseases.

Background

COVID-19 poses an extraordinary challenge to the public healthcare system in Australia. One of the greatest such challenges will be the pressure upon hospitals to support people affected with severe forms of the disease. Recent experience in Italy has demonstrated the overwhelming demand for intensive care services that can occur at the peak of the epidemic, resulting in otherwise preventable deaths due to a lack of available ventilators and an overstretched health workforce (1). The trajectory of the epidemic in Australia appears to be lagging by several weeks behind many European and North American countries, in part due to the travel bans introduced early in the epidemic. The situation is changing extremely rapidly, and Australian government strategy is currently aimed at mitigating, rather than suppressing or eliminating, the infection from the general population (2). However, unless a vaccine is developed, it appears likely that the epidemic will spread rapidly within the community (3). The effectiveness of current and proposed non-pharmaceutical interventions (such as social distancing measures) is uncertain and highly dependent on the extent to which they are implemented. Modelling studies can provide valuable insights into the likely course of the epidemic, and can be particularly useful in anticipating resourcing requirements – such as the demand for intensive care services at the peak of the epidemic. A modelling group at Imperial College London, a WHO Collaborating Centre for Infectious Disease Modelling, has modelled the effect of different mitigation policies upon peak healthcare demand (4). We extrapolate the findings from the Imperial College model to the New South Wales population, and explore the effect of varying the reproduction number (Ro) upon the timing of the peak of the epidemic.

Methods

The Imperial College model adopted a number of assumptions regarding the natural history and clinical management of the COVID-19 epidemic. These assumptions included an incubation period of 5.1 days, infectiousness from 12 hours before symptom onset, a mean generation time of 6.5 days, a basic reproduction number (R_0) of 2.4, and a doubling time of 5 days. The model applied age-stratified hospitalisation ratios and infection fatality ratios (IFR), with an average IFR of 0.9%, with 4.4% of infections hospitalised. Average duration of hospitalisation was 8 days (no critical care) or 16 days (with 10 in ICU) if critical care was required. 30% of hospitalised cases required critical care, and the mean duration of hospitalisation was 10.4 days.

The study modelled several interventions applied from 1st April 2020: (a) no public health measures, (b) case isolation only, (c) case isolation and household quarantine, and (d) case isolation, quarantine of all household contacts of a symptomatic case and social distancing of over 70 year-olds. An individual-based simulation model was used.

We applied the outcomes of the Imperial College model to the population of NSW, accounting for local demographic distribution (5). The age distribution between the two settings is similar, shown in the Supplementary Figure (6, 7).

SEIR model of healthcare utilisation

We also performed a simple SEIR (susceptible-exposed/incubating – infected-removed) model in order to explore the effect of varying the reproduction number (Ro, which may be reduced by effective social distancing measures). The modelled outcome was hospitalised cases, and ICU cases, per 100,000 population. We modelled two scenarios: (a) no intervention, with a Ro of 2.4, and (b) social isolation policies, leading to a Ro 1.6, both with a start prevalence on 1st March 2020 of 2 persons per million. Detailed model parameters are included in the Supplementary Table.

Results

Application of the Imperial College Model to NSW

As of 29th March 2020, the case notification rate is lower in NSW (22.8 cases per 100,000) compared with the UK (26.2 cases per 100,000 cases)(8, 9). The Supplementary Figure compares the age distribution between the UK and NSW. Current mortality in the UK is 1.6 deaths per 100,000 and 0.1 deaths per 100,000 in NSW. Extrapolating the findings of *Ferguson et al* to the NSW population of 7,739,274 in 2016, there would hypothetically be a total of 69,563 deaths in NSW over the course of the pandemic, under the scenario with no interventions. Based upon the Imperial College modelling, if mitigation efforts are implemented the total demand for ICU beds in NSW would be at least 6,965 beds. Table 1 shows the estimated number of critical care beds required at the peak of the epidemic to the NSW population, under different scenarios by Local Health District.

Supplementary Table S2 shows the estimated cumulative hospitalisations, ICU admissions and deaths in one Local Health District (Sydney LHD) under an optimal mitigation scenario comprising case isolation, household quarantine and social distancing of over 70 year-olds.

Outcomes of the SEIR model

Figure 1 shows the projected hospitalisations and intensive care beds required under the scenario of no mitigation, and with social distancing. Table 2 shows the projected hospitalisations and intensive care bed requirements under the two scenarios. Without social distancing measures (Ro=2.4), we may expect a peak of over 450 requiring hospitalization per 100,000 and around 150 people requiring critical care per 100,000 (a total of 11,791 ICU beds in NSW). This represents a 1,349% of the baseline ICU capacity in NSW. According to the scenario with no mitigation, peak transmission would be late June and peak hospital utilization early July, with 16% of the population in the potentially symptomatic phase (though only a proportion was modelled to exhibit symptoms).

Under the scenario of increased social isolation (R_o = 1.6), the peak infection will shift to early October and peak ICU utilization will shift to mid-November and would be around one third the size of the business-as-usual (no mitigation) peak, with around 5% of the population in the potentially symptomatic phase, with 180 people per 100,000 population in hospital (14,149 beds in NSW) and 65 per 100,000 in ICU (correlating to 5,109 ICU beds in NSW). This represents 585% of the state's baseline ICU capacity prior to the epidemic.

Discussion

We have used two different modelling methods to estimate peak demand for critical care services in NSW during the COVID-19 epidemic. Both approaches showed an overwhelming burden of COVID-19 upon the healthcare system. The mismatch between the estimated demands and the available ICU beds is stark. Prior to the current epidemic, there were 874 intensive care unit (ICU) beds in NSW (8.92 per 100,000 population) (10). Even with a doubling of existing services, the available supply is estimated to be substantially less than the peak requirement of 6,965 beds (Imperial College model) or 5,109 beds (our SEIR model). Data from both models indicate that hospitals and ICU facilities are likely to be overwhelmed unless transmission can be reduced significantly.

The UK and NSW are at a similar point in their epidemics, on the basis of per-capita notifications. However, the mortality for NSW is just 6% of that in the UK, per capita, suggesting that the case detection may be currently be higher in Australia. The peak of the epidemic in the UK is forecast to occur between mid-May and mid-June 2020, with a later peak if interventions are introduced. Our SEIR model also suggested that partially effective social isolation would delay the peak by up to 12 weeks.

Our approach has several limitations. Modelling studies depend upon the assumptions upon which they are based, and parameters including the current reproduction number (R_o) remain uncertain as the epidemic is still unfolding. The trajectory of the epidemic, and the magnitude of peak ICU demand will be highly dependent upon the effectiveness of mitigation strategies. The present report does not estimate the effect of more intensive suppression strategies, which would be likely to reduce the peak ICU requirement. Despite the usual limitations inherent in modelling studies, such studies have an important role in informing contingency planning, where applicable parameters are available. Further modelling is needed to inform resource planning for the COVID-19 epidemic in Australia, including for critical care services. Such models will help to inform the public debate regarding the timing, intensity and duration of mitigation strategies.

Conclusion

These two models demonstrate the critical importance of effective COVID-19 containment strategies, and highlight the importance of urgent investment in the resources required to support surge capacity for critical care services in NSW. The timing and magnitude of the peak demand will be strongly dependent upon the effectiveness of mitigation strategies. Ongoing surveillance of transmission in the community will be essential to allow healthcare services to anticipate the effects of national COVID-19 mitigation policies upon healthcare resource requirements.

Table 1: Estimated Intensive Care Unit beds required at the peak of the initial wave of infections, applying *the* Imperial College study to the NSW population

Mitigation strategies	Estimated ICU beds required at the peak of epidemic[+]										Number of ICU beds in NSW at baseline**	Percentage of ICU beds at peak in NSW, compared to baseline
	ICU Beds required per 100,000, according to the Imperial College model	SLHD	SWSLHD	SESLHD	Illawarra	WSLHD	NSLHD	CCLHD	Other	All NSW		
Unmitigated	275	1,805	2,652	2,514	1,115	2,609	2,514	922	7,152	**21,283**	874	2435%
Closing schools and Universities	240	1,576	2,314	2,194	973	2,277	2,194	805	6,242	**18,574**	874	2125%
Case isolation	190	1,247	1,832	1,737	771	1,802	1,737	637	4,942	**14,705**	874	1682%
Case isolation and household quarantine	125	821	1,205	1,143	507	1,186	1,143	419	3,251	**9,674**	874	1107%
Case isolation, household quarantine,	90	591	868	823	365	854	823	302	2,341	**6,965**	874	797%

social distancing of >70 year olds												
Total population	--	656,460	964,342	914,021	405,534	948,584	914,233	335,309	2,600,791	**7,739,274**	**--**	**--**

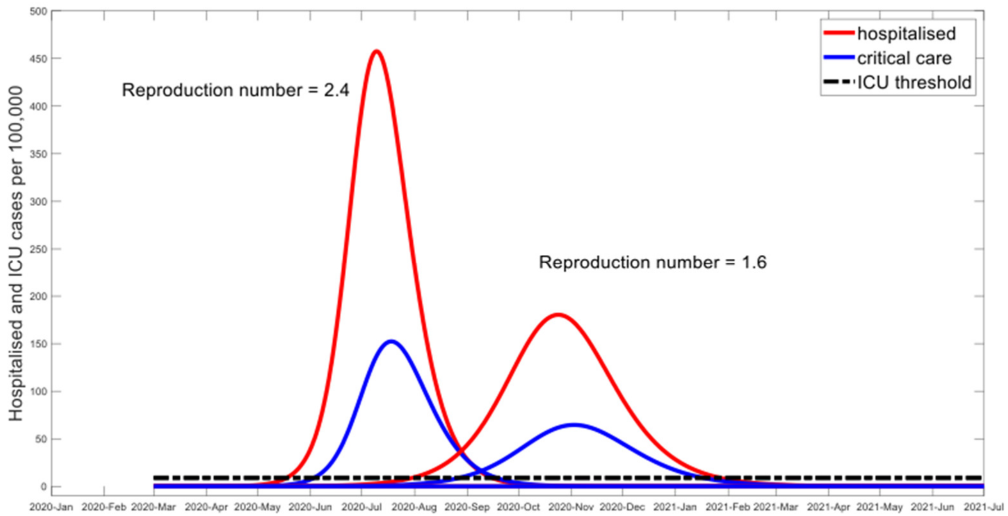
+Based upon extrapolation of the findings of the Imperial College study (4).
*Population of NSW Local Health Districts in 2016 (5)
**Estimates prior to the COVID-19 epidemic (10).

Table 2: Estimated Intensive Care Unit beds required at the peak of the initial wave of infections in NSW, with the SEIR model

Transmission number R_o (scenario)	Hospitalisations per 100,000 population	Number of hospitalisations required in NSW*	ICU beds required per 100,000 population	Number of ICU beds required in NSW	Number of ICU beds available in NSW prior to the outbreak	Percentage of ICU beds at peak, compared to baseline
2.4 (no mitigation)	450	35,375	150	11,792	874	1,349%
1.6 (mitigation)	180	14,150	65	5,110	874	585%

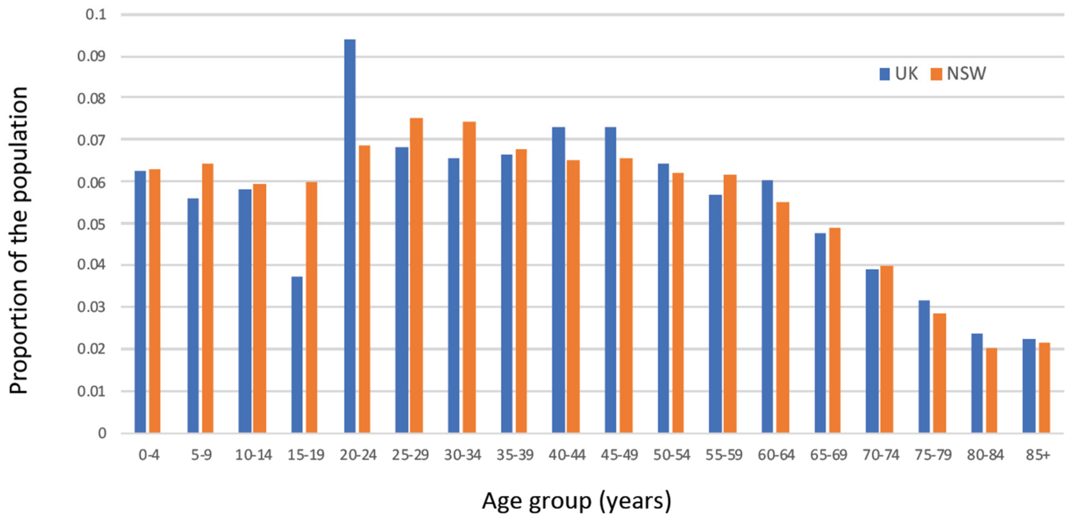
*Given a population of NSW of 7,861,068 (5).

Figure 1: The estimated number of hospitalised and ICU cases during the COVID-19 epidemic using a SEIR model



The estimated number of hospitalised and ICU cases during the COVID-19 epidemic using a SEIR model

Figure S1: A comparison of the age of the Australian and United Kingdom populations



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Supplementary Appendix

Table S1: Model parameters

Parameter	**Value**
Reproduction number	R_{eff}
Business as usual	2.4
Flatten the curve and achieve herd immunity	1.6
Contain and control	0.8
Duration of time in early incubation, prior to being infectious	$(\sigma_1)^{-1} = 3.6$ days
Duration of time infectious prior to symptoms	$(\sigma_2)^{-1} =$ half a day
Early infectious period	$(\gamma_1)^{-1} = 2$ days
Late infectious period	$(\gamma_2)^{-1} = 5.68$ days
Duration of time in hospital	$(\gamma_h)^{-1} = 8$ days

Duration of time in ICU	$(\gamma_{icu})^{-1} = 10$ days
Initial conditions	2 per million people in latent phase at 1st March 2020
Proportion of people who go to hospital	3.3%
Proportion of hospitalisations that go to ICU	30%
Per infectious person daily infectiousness	$\beta = \frac{R_{eff}}{\sigma_2 + \gamma_1 + \gamma_2}$
Force of infection	$\beta s(t)^{\alpha} i(t)$
Dissipation of infectiousness as the proportion of the population susceptible reduces	$\alpha = 1.18$

Table S2: Estimated total hospitalisations, ICU beds and deaths, without mitigation strategies, applying *the* Imperial College findings to the Sydney LHD population

		Base case (unmitigated epidemic)			**Optimal mitigation (reducing critical care by 2/3, deaths by 1/2)**	
Age group (years)	**Population of SLHD**	**Total hospitalisations**	**Total ICU requirements**	**Total Deaths**	**Total ICU requirements**	**Total Deaths**
0-9	74,100	74	4	1	1	1
10-19	54,610	164	8	3	3	2
20-29	114,680	1,376	69	3	23	2
30-39	125,010	4,000	200	10	67	5
40-49	90,860	4,452	280	14	93	7
50-59	72,060	7,350	897	432	299	216
60-69	53,210	8,833	2,420	1171	807	585
70-79	33,190	8,065	3,484	1693	1,161	846
80 and over	21,810	5,954	4,221	2028	1,407	1,014
Total	**639,530**	**40,269**	**11,584**	**5356**	**3,861**	**2,678**

SLHD = Sydney Local Health District. *Population age distribution of Sydney LHD reported in 2015.

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