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Supporting Information

Supplementary methods and results

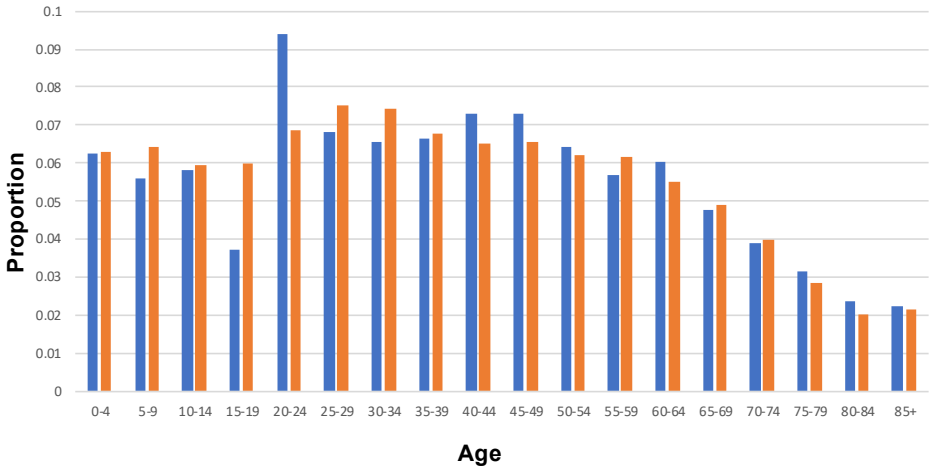
**This appendix was part of the submitted manuscript and has been peer reviewed.
It is posted as supplied by the authors.**

Appendix to: Fox GJ, Trauer JM, McBryde E. Modelling the impact of COVID-19 on intensive care services in New South Wales. *Med J Aust* 2020; doi: 10.5694/mja2.50606.

Description of the Imperial College model

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.[1] The Imperial College model adopted a number of assumptions regarding the natural history and clinical management of the COVID-19 epidemic. We applied the outcomes of the Imperial College model to the population of NSW, accounting for local demographic distribution.[2] The age distribution between the two settings is similar, shown in Figure 1.[3,4]

Figure 1. Comparison of the age of the Australian and United Kingdom populations



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 1 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.

Description of the SEIR model

We developed a simple SEIR-type compartmental model (susceptible (S), exposed/incubation period (E), infectious (I) and removed(R)) (Figure 2). The standard model is modified to allow for pre-symptomatic transmission during the incubation period (E_2), a delay between the onset of symptoms and presentation to healthcare (I_1), diagnosed disease (I_2), hospitalization (H), and ICU admission (ICU). In this model, compartments E_2, I_1 and I_2 are infectious. The force of infection is therefore given by:

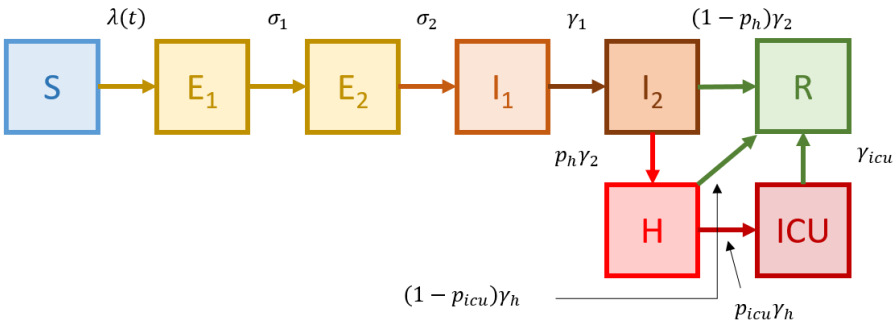
$$\lambda(t) = (E_2(t) + I_1(t) + I_2(t))\frac{\text{Reproduction number}}{\text{Infectious period}}$$

Where:

$$\text{Infectious period} = \frac{1}{\sigma_2} + \frac{1}{\gamma_1} + \frac{1}{\gamma_2}$$

We also performed a simple SEIR (susceptible-exposed/incubating – infected-removed) model in order to explore the effect of varying the basic reproduction number (R_0) which may be reduced by effective social distancing measures and subsequently is called the effective reproduction number (R_{eff}). The modelled outcome was hospitalised cases, and ICU cases, per 100,000 population. We modelled two scenarios: (a) no intervention, with a R_0 of 2.4, and (b) social isolation policies, leading to a R_{eff} of 1.6, both with a start prevalence on 1 March 2020 of 2 persons per million. Detailed model parameters are included in Table 1.

Figure 2. The modified SEIR model



Sensitivity analysis

We conducted a partial rank correlation coefficient study of nine key model parameters; Reproduction number, probability of hospitalisation, duration of hospitalisation, probability of being admitted to ICU given hospitalisation, duration of ICU admission, time in E_1, time in E_2, time in I_1, time in I_2 against four key outcomes; peak hospitalisation numbers, peak ICU numbers, time to peak hospitalisation and time to peak ICU as shown in Figure 3.

Limitations

Our approach has several limitations. Modelling studies depend upon the assumptions upon which they are based, and parameters including the current reproduction number 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.

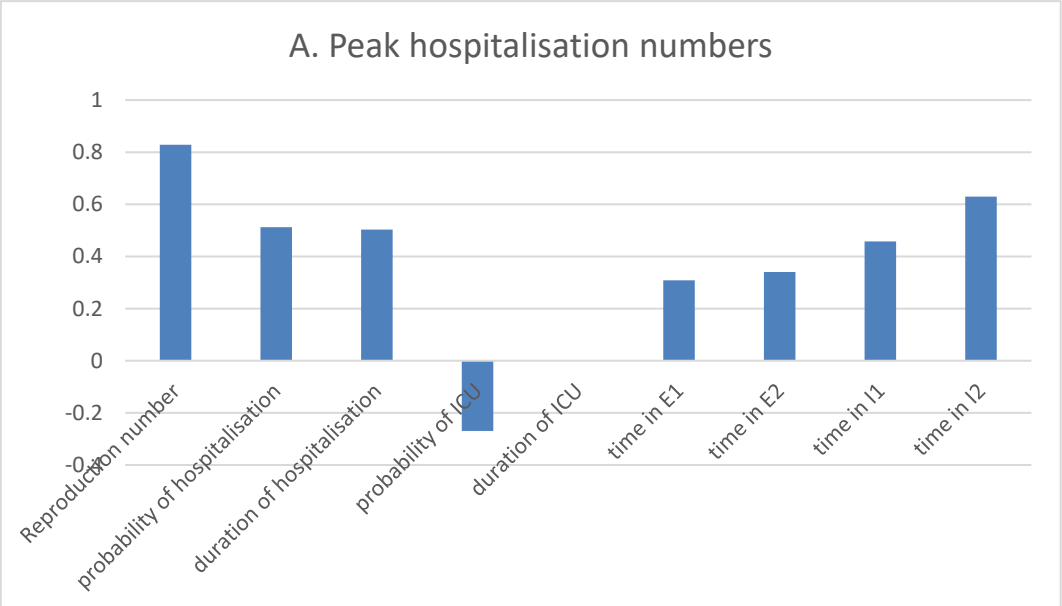
Ethics approval

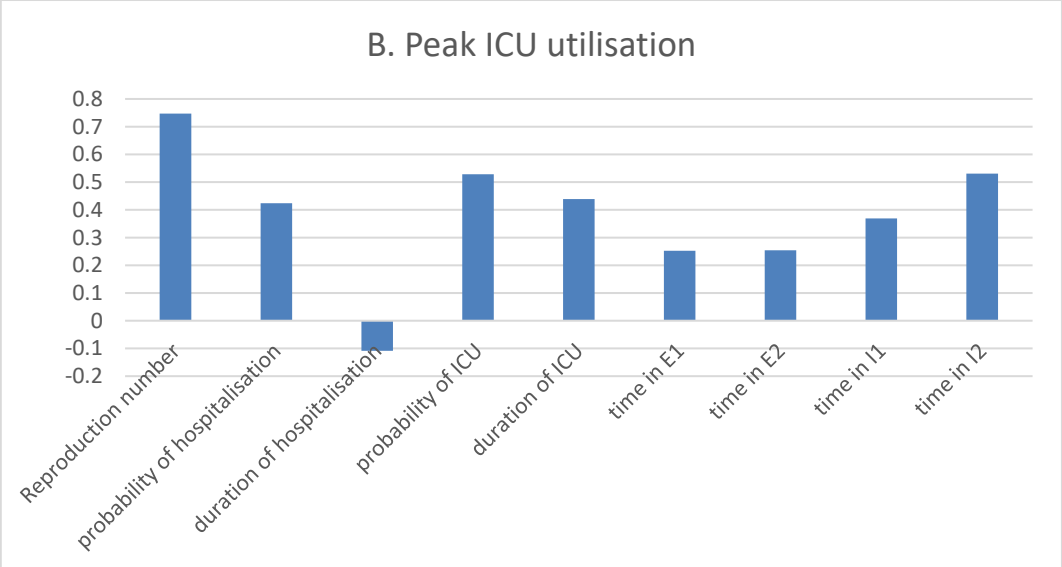
This modelling study did not enrol participants, and so ethics review was not warranted.

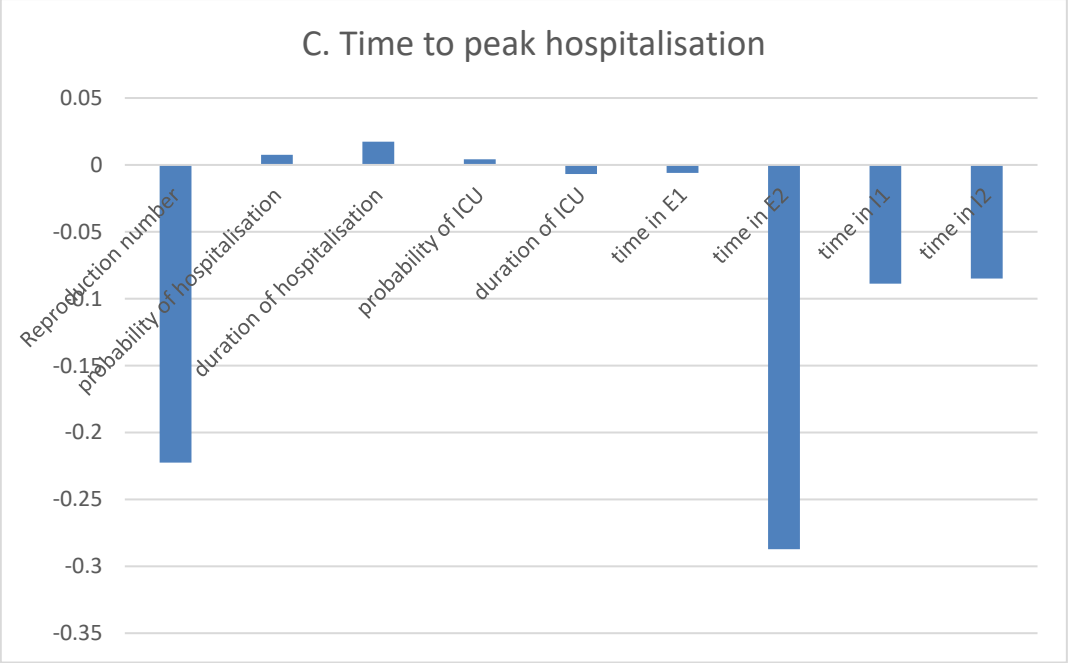
Table 1. Parameters of the model

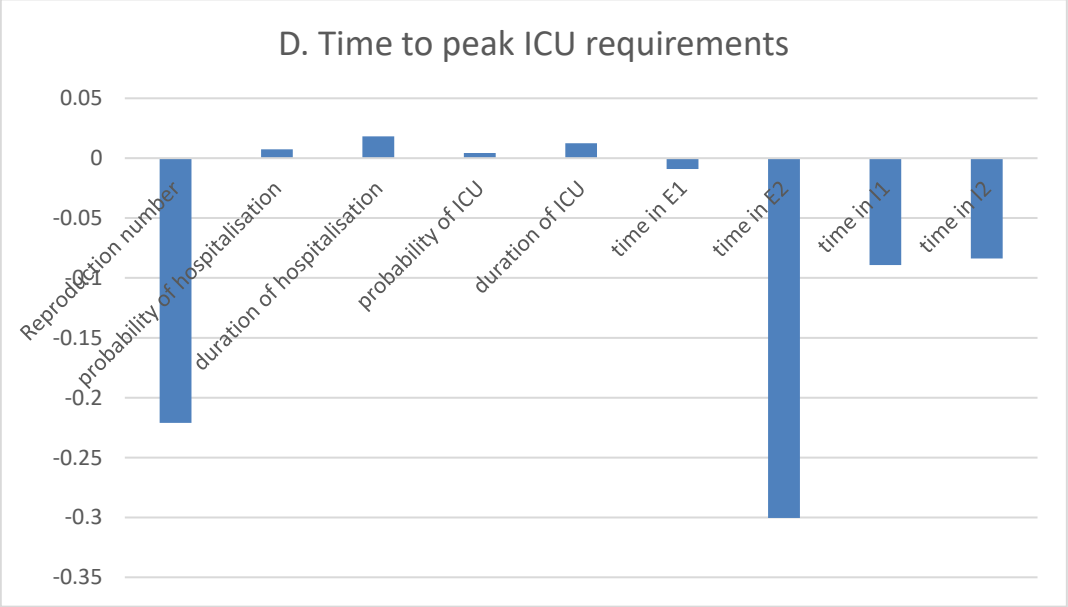
Parameter	Value	Explanation
Reproduction number	R_{eff}	Typical number of secondary infections per infected person
Business as usual	2.4	Reproduction number in the absence of interventions
Flatten the curve and achieve herd immunity	1.6	Reproduction number under a combination of home isolation of suspect cases, home quarantine of those living in the same household as suspect cases, and social distancing of the elderly and others at most risk. Vigorous contact tracing and testing. Example countries achieving a similar reproduction number: Japan,[5] Hong Kong[5]
Duration of time in early incubation, prior to being infectious	$(\sigma_1)^{-1} = 3.6$ days	Reference 1
Duration of time infectious prior to symptoms developing	$(\sigma_2)^{-1} =$ half a day	Reference 1
Early infectious period	$(\gamma_1)^{-1} = 2$ days	Symptomatic period prior to detection[1]
Late infectious period	$(\gamma_2)^{-1} = 5.68$ days	Remaining infectious period[1]
Duration of time in hospital	$(\gamma_h)^{-1} = 8$ days	To match observations in Italy (personal correspondence described in Ferguson et al[1])
Duration of time in ICU	$(\gamma_{icu})^{-1} = 10$ days	To match observations in Italy (personal correspondence described in Ferguson et al[1])
Initial conditions	No local cases at start of epidemic 25 January 2020	Data sourced from www.COVID19data.com.au[6]
Proportion of people hospitalised	6.7–15.5% of cases 3–7% of all infections	Reference 7 falls within this range
Proportion of hospitalisations admitted to ICU	30%	Reference 1
Per infectious person daily infectiousness	$\beta = \frac{R_{eff}}{1/\sigma_2 + 1/\gamma_1 + 1/\gamma_2}$	In this model, a simplifying assumption of equal infectiousness was used for all stages of infection until hospitalisation
Force of infection	$\beta S(t)^{\alpha} I(t)/N$	Daily number of incident infections, where N is the population of Australia and s(0)=N
Dissipation of infectiousness as proportion of population susceptible reduces	$\alpha = 1.18$	Calibrated to Ferguson et al[1] to allow an R_{eff} = 2.4 and a final size =81%
Probability of symptoms given infection	0.45 (45%)	References 1,7

Figure 3. Partial rank correlation coefficients for nine model parameters against four model outcomes









It is evident that the size of both peaks (C, D) are highly sensitive to the reproduction number (as expected) and also highly sensitive to the time spent in the hospital/ICU states of the model. The time to peak is negatively correlated with the reproduction number (as reflected in figure 1) and also to the length of the stages of infection, particularly E2.

Supplementary results

As of 29 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] Figure 1 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. Table 2 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.

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 2. 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	1376	69	3	23	2
30–39	125,010	4000	200	10	67	5
40–49	90,860	4452	280	14	93	7
50–59	72,060	7350	897	432	299	216
60–69	53,210	8833	2420	1171	807	585
70–79	33,190	8065	3484	1693	1161	846
80 and over	21,810	5954	4221	2028	1407	1014
Total	**639,530**	**40,269**	**11,584**	**5356**	**3861**	**2678**

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

Table 3. Estimated intensive care unit beds required at the peak of the initial wave of infections in NSW, with the SEIR model

Transmission number R_0 (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	1349%
1.6 (mitigation)	180	14,150	65	5110	874	585%

* Given a population of NSW of 7,861,068.[9]

Table 4. Sensitivity analysis of estimated intensive care unit beds required at the peak of the initial wave of infections in NSW, with the SEIR model

Transmission number R_0 (scenario)	Assumed case hospitalisation rate	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)	5%	290	22,000	100	7300	874	840%
	10%	570	43,000	190	15,000		1700%
	15%	860	65,000	290	22,000		2500%
1.6 (mitigation)	5%	112	8500	40	3000	874	340%
	10%	225	17,000	81	6100		700%
	15%	340	25,000	120	9000		1000%

References

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