

Estimating the future burden of Long-COVID in Australia

Authors Valentina Costantino, Damian Honeyman, Adriana Notaras, Raina MacIntyre

The Biosecurity Program, The Kirby Institute, UNSW.

Terms of Reference Point 3 “Research into the potential and known effects, causes, risk factors, prevalence, management, and treatment of long-COVID and/or repeated COVID infections”

Summary

Australia faces a growing burden of chronic disease due to SARS-COV-2. This study will be developed in a more detailed format, but is presented here as early data to inform the parliamentary inquiry. Using a mathematical model, we estimated the age-specific burden of Long COVID in Australia to October 2023. The model does not consider re-infections, so is a minimal estimate. The model estimated that with a vaccine-only policy and no other efforts to mitigate transmission, almost all Australians will be infected at least once in the time window from January 2021 to August 2023. The total people with long-COVID by December 2023 is 1,323,482, with 43,910 of these being children 0.4 years of age. This does not include the burden of long-COVID caused by reinfections. Over 3% of the 0–4-year-old age group are estimated to never recover, while almost 1% of 5–19-year-old and over 6% for the population 20+ years old were estimated to never recover. The true burden will be higher than this, as reinfections will add to the burden of Long-COVID. A vaccine plus strategy, which includes increased access to testing, isolation, masks and safe indoor air, will mitigate the continued infection of Australians with SARS-COV-2 and help reduce the long-term burden of long-COVID. Models of long-COVID projections can be used to test the impact of infection prevention and control strategies on future burden of long-COVID.

Introduction

Long-COVID is a serious concern for the community, public health professionals and healthcare systems internationally, with rapidly accumulating evidence that SARS-COV-2 has effects on many organ systems beyond the acute infection (1-3). The term “long COVID” is defined by symptoms persisting beyond the acute infection, but the pathophysiology of these symptoms may range from respiratory, cardiac, neurocognitive to immunological or other causes.

Neurological symptoms (e.g. memory disturbances, weakness), possible cardiac disturbances (e.g. chest pain, increased heart rate) and respiratory symptoms (e.g. cough) are being reported at increased rates among individuals who have had a previous COVID-19 infection compared with those who have no previous reported infection (4). Additional symptoms include fatigue, shortness of breath, palpitations, anxiety, and depression with varying levels of persistence one month and up

until 12 months following initial infection (5-9). A greater level of severe illness during hospitalization for initial infection has shown to contribute to more extensively diminished pulmonary capacities and unusual chest imaging presentations (9). The prevalence of long-COVID is estimated to range from 15 – 30% in adults aged 18 – 64 years old, and between 26.6% - 45.4% in adults aged 65 years and over (5, 7-38). However, the data varies according to study and population size with some studies reporting long-COVID prevalence rates up to 80% among adults (5, 7-38).

A range of health effects, for varying lengths of time (weeks to months) after infection are being reported after COVID-19, with those reporting symptoms experiencing impairment of their ability to conduct normal day-to-day activities (1, 4). The use of vaccines is protective against development of long-COVID, but that protection may be around 15% (39). Research suggests that the incidence and severity of long-COVID may be influenced by the severity of the acute COVID-19 infection, variants of concern, vaccination status prior to infection, certain comorbidities, age, sex, reinfection, and antiviral treatment (2, 4, 10, 40, 41). Long-COVID is more common in adults, and in people who have suffered severe infection (42). However, it can also occur after mild infection and in children (6, 43, 44). For children it is unknown if the longer term sequelae of long-COVID and repeated infections will have long-lasting impacts on not only their health, education, and social development. The prevalence of long-COVID amongst children and adolescents between the ages of 0 and 18 varies between studies from 4 to 66% among survivors who were 4 or more weeks since initial infections (6, 19, 43, 45-57). Rates of long COVID increase among both children and adolescents and adults if they have been hospitalized in their initial infection, suggesting that more severe initial illness is associated with a greater risk of developing long-COVID (6, 58).

Evidence is now accruing that reinfection results in worse outcomes and may increase the risk of long-COVID. An online survey found that in those who had been reinfected, long-COVID symptoms became more severe in 80% of respondents after re-infection (40). Of those who had recovered from long-COVID, reinfection caused a resurgence of long-COVID in 60% of respondents (40). An increased number of vaccines may also be associated with lower long-COVID prevalence: those who were unvaccinated had the highest long-COVID prevalence at 41.8%, decreasing to 30% in those with 1 dose, then 17.4% in those with 2 doses and down to 16% in those with 3 doses (59). Australia has >95% two-dose vaccine coverage for people 16 years and over, 72.3% for a third dose and 42.1% for a fourth dose (60). Children 0-4 years are not recommended for vaccination unless severely immunosuppressed. Whilst vaccination with a fourth dose was recommended for those aged 65 and older, residents in aged care facilities, people over 16 years of age with severe immunocompromise and Aboriginal and Torres Strait Islander people aged 50 years and older in March 2022 (61), booster doses for those aged 16 to 64 were not recommended until July 2022 (62). A fifth dose was recommended for 30-49 years and 50+ years in November 2022 for aged care residents, people with chronic medical conditions and multiple comorbidities (63). Children aged 5-15 years are currently not recommended to have a booster beyond their primary course unless severely immunocompromised, have a disability or multiple health conditions, adolescents aged 16-17 years were recommended in October 2022, to have a booster 3 months after their primary course (64). Despite these recommendations, gaps remain between the number of people eligible for boosters and those who've received them and given the surge in COVID-19 variants of 2022 primary schedules and boosters are important in the arsenal to prevent severe disease and long-COVID.

Interestingly, numerous studies have found higher rates of long-COVID among female COVID-19 survivors (7, 9, 24). Pre-existing medical conditions have too been associated with an increased risk of long-COVID, including dyslipidemia, an increased body mass index and pre-existing lung disease such as asthma and COPD (2, 24). One study investigating symptoms at 6, 12 and 18-month intervals found 6% had not recovered and only 42% recovered partially (13). Such factors and their relationship with long-COVID are important to consider when treating COVID-19 patients, assessing vulnerability to long-COVID and tailoring interventions that may reduce susceptibility to long-COVID. Long-COVID is predicted to place an ongoing burden on health care providers and global health now and into the future, accompanied by societal and economic impacts (3, 65). In the UK, one in four employers report their workforce is affected by Long-COVID (66). Variations in estimates of Long-COVID reflect different definitions of long-COVID, different measurement, varying population age structure, and different rates of population vaccination (3). There remain gaps in knowledge regarding long-COVID, including the effects of long-COVID beyond 12 months after diagnosis (67). Projections of rates of long-COVID into the future are crucial to government, researchers, healthcare professionals, public health staff, economists and policy makers with the tools and knowledge to prepare for preventing, controlling, and treating long-COVID long-term.

Aim: To estimate the age-specific burden of Long-COVID in Australia over a 12-month period.

Methods

To assist public health and health department capacity building to manage the burden of long-COVID in Australia, we developed a modeling method to estimate the future burden of long-COVID in Australia. The model estimates the time for the entire population to be infected at least once from January 2021 and estimates the burden of long-COVID for the subsequent 12 months, factoring in rates of recovery from long-COVID. The model does not include reinfections, so is a minimal estimate. We assumed Australia would continue with a vaccine-only strategy, with minimal other mitigations.

Estimates of COVID-19 incidence in Australia based on notified data are not reliable due to decreased testing and lack of mandatory reporting of a positive RAT test, which would underestimate the incidence (68). There have been modelling studies to estimate the true number of new cases using different data such as hospitalization, testing and death rates (69).

We used the results from a serological survey using Australia blood donors in three different time points (70) for adults, and in a single time point for children (71) to estimate true infection rates. The first time point was between 23 February and 3 March 2022, the second time point was between 9-18 of June 2022 and the third time point was between 23 August and 2 September. The estimated proportion of the population with at least one COVID-19 infection in these three time points is shown in Table 1. For the age group 0-19, we only had the seroprevalence at a single time point, September. As such, we estimated the values for the two missed time points for children using relative changes in seropositivity adults (see Table 1).

To estimate the proportion of the population living with long-COVID-19 symptoms over time, we used an adjusted SIR model (Figure 1), where the S compartment represents people that have never

had COVID-19 in 2022. To inform this compartment we used the age specific population for Australia in 2020-2021 (5). The I compartment represents the people that had covid at least once in 2022, and this compartment and the rate of people passing from S to I, have been estimated by interpolating the three values from the serosurvey surveillance results over time in 2022. For Table 2, to estimate the age specific proportion of people suffering from long-COVID symptoms, we have collected data on the prevalence of long-COVID derived from studies focusing on children, adolescents, and adults (5, 57). If the specific article compared cases with controls, prevalence was calculated to identify the difference (cases minus controls). This method was used for the symptoms for up to 3 months. For symptoms up to 12 months, we used the estimated percentage of those who have no recovery at 12 months and subtracted this from the prevalence (13).

Figure 1 shows the SIR model diagram used.

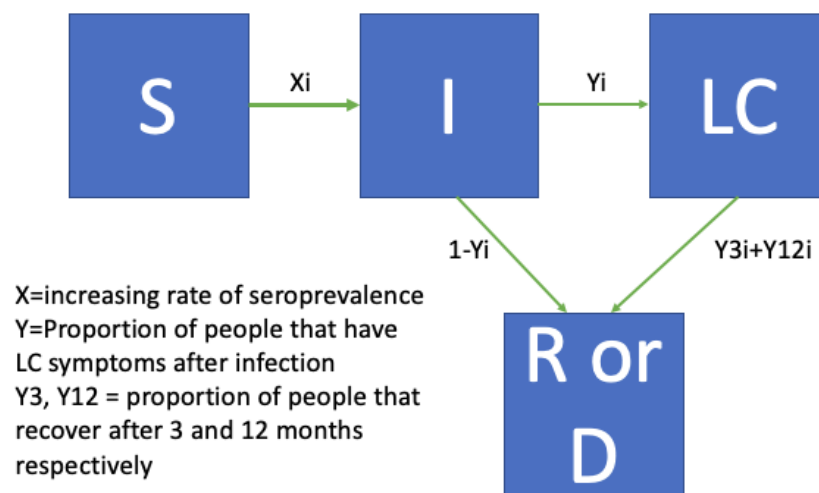


Figure 1: SIR model diagram with susceptible (S), infected (I), with long COVID symptoms (LC) and recovered or dead (R or D), while every compartment is age specific following $i=1,...,9$ age groups and the time t is in months.

Table 1: Data used for the estimation of increase in seropositivity over time in months (70, 71).

Age group	March 2022	June 2022	September 2022
0-19	15.8%	45%	64%
20-29	27.2%	61.7%	79.7%
30-39	21.7%	52.6%	72.5%
40-49	16.1%	47.5%	68.3%
50-59	11.9%	38.9%	63%
60-69	8.3%	30.2%	49.2%

70+	6.4%	25.7%	41.6%
All	17%	46.2%	65.2%

Table 2: Age specific rates of Long-COVID for at 3 months and 12 months

Age groups	Symptoms up to 3 months	Symptoms up to 12 months
0-4	12.8% (57)	6.144% (13, 57)
5-9	4.4% (57)	2.112% (13, 57)
10-19	4.7% (57)	2.256% (13, 57)
20-59	20.8% (5)	9.984% (5, 13)
60+	26.9% (5)	12.912% (5, 13)

Results

Figure 2 shows the projection by age group of the proportion of people will have COVID-19 at least once up to August 2023. The model estimated that almost all Australians will be infected at least once in the time window from January 2021 to August 2023. As shown in Figure 2, the seroprevalence in older age groups (60+) increases at a slower rate than younger age groups in accordance with less contacts in those age groups.

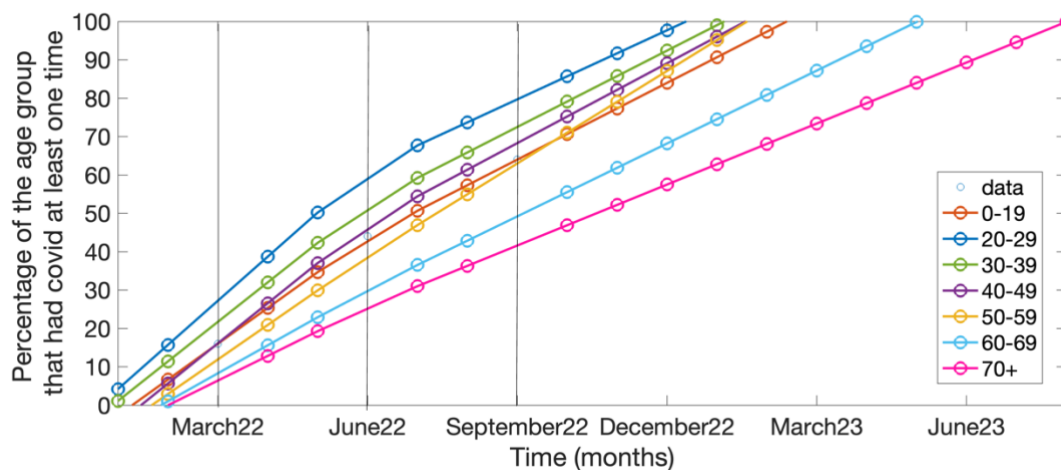


Figure 2: Estimation of age-specific seroprevalence over time, using the values over time listed in Table 1.

Figure 3 shows the monthly number of people suffering from long-COVID symptoms in each month from January 2022 until August 2023 with a peak and then waning which reflects recovery of a proportion of people from Long-COVID. However, the data only included people that got infected in the time window from January 2022 to January-August 2023 depending on age-groups (See Figure 2).

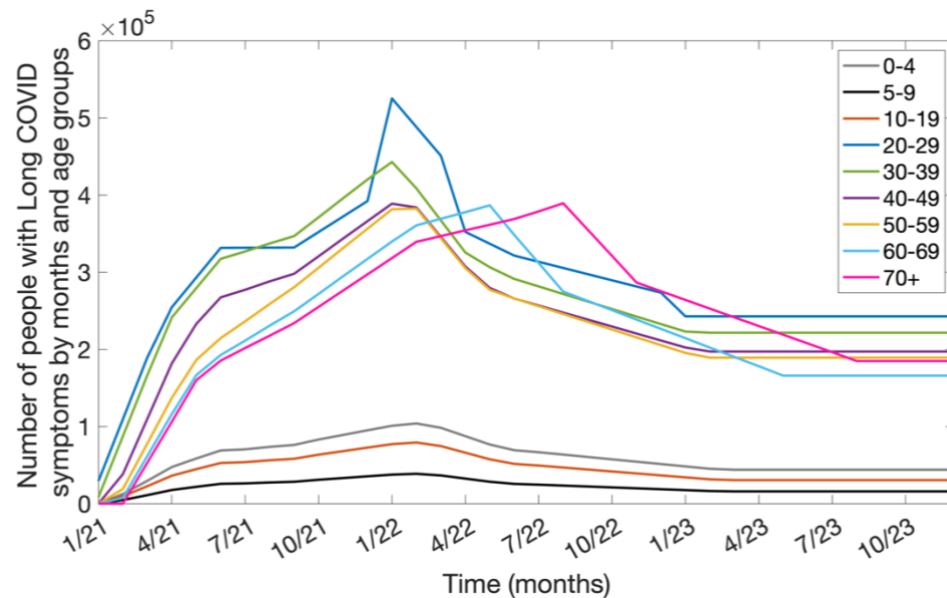


Figure 3: Number of people with long-COVID symptoms arising from infections between January 2022 and August 2023.

Table 3 shows the monthly estimated number of people with long-COVID in three age groups - 0-4 years (mostly unvaccinated), 5-19 years (partially vaccinated) and 20+ (mostly vaccinated). The total people with long-COVID by December 2023 is 1,323,482, with 43,910 of these being children 0.4 years of age. This does not include the burden of long-COVID caused by reinfections. Over 3% of the 0–4-year-old age group are estimated to never recover, while almost 1% of 5–19-year-old and over 6% for the population 20+ years old were estimated to never recover.

Table 3: Number of people with long-COVID symptoms by months and three age groups, 0-4 (unvaccinated), 5-19 (partially vaccinated) and 20+ (mostly vaccinated).

2021	0-4	5-19	20+	2022	0-4	5-19	20+	2023	0-4	5-19	20+
January	0	0	36950	January	100870	77706	2546140	January	48240	35253	1326470
February	12550	9671	277370	February	103910	79906	2500220	February	45160	32737	1291860
March	29600	22806	693810	March	98250	75357	2314740	March	43910	31722	1277270
April	47400	36518	1091020	April	87450	66835	2067630	April	43910	31722	1262680
May	58490	45057	1381720	May	76600	58276	1957760	May	43910	31722	1247850
June	68920	53094	1581600	June	69230	52380	1844160	June	43910	31722	1247850
July	70350	54191	1669310	July	66600	50240	1752640	July	43910	31722	1247850
August	73550	56662	1761070	August	63570	47761	1659870	August	43910	31722	1247850
September	76070	58602	1848780	September	60480	45244	1597880	September	43910	31722	1247850
October	83070	63994	1994810	October	57400	42728	1535890	October	43910	31722	1247850
November	89010	68567	2142620	November	54360	40249	1473130	November	43910	31722	1247850

December	95030	73209	2288660	December	51280	37732	1411150	December	43910	31722	1247850
----------	-------	-------	---------	----------	-------	-------	---------	----------	-------	-------	---------

Discussion

Australia faces a growing burden of chronic disease due to SARS-COV-2. This study will be developed in a more detailed format, including economic projections for Australia, but is presented here as early data to inform the parliamentary inquiry.

Vaccinating children 0-4 years should be considered based on the modelled outcomes for this age group in Australia, and the higher incidence of long-COVID in this age group compared to older children (57). The higher incidence of Long-COVID among the youngest children in Denmark may reflect this age group being unvaccinated.

Proactive booster policies should also be considered to ensure wider access to 3rd and 4th doses. Despite concerns about original antigenic sin, no clinical trial shows that boosters reduce protection. In fact, they increase protection (72).

In this study we found that cumulative infections over 12-18 months can result in a very high proportion of people living with long-COVID. Over 3% of the 0–4-year-old age group are estimated to never recover, while almost 1% were estimated to never recover in the 5–19-year-old age group and over 6% for the population 20+ years old.

This study has some limitations. To identify the prevalence of long-COVID in children, adolescents, and adults we selected large scale studies with community-based selection of participants, and ensured estimates were based on largely vaccinated population (5, 57). The prevalence rates are based on countries where population studies were conducted, including the United States of America and Denmark. Each country had differing COVID-19 rates and population vaccination rates when compared with Australia (73). However, given the robustness of the studies and comparable economic and life expectancies between the countries, we believe that these prevalence rates are generalisable for an Australian population (74). Data from an [Australian survey](#) suggested 29% of people suffer long COVID, but we used lower and more conservative estimates. We did not consider re-infection in the model, so the results presented are a minimal estimate. We also did not consider the impact of a new variant of concern with greater immune evasion.

Similar to other modelling studies done in Australia, our results suggest that hundreds of thousands of people across the country will have long-COVID (75). Modeling from the Institute for Health Transformation at Deakin University predicted between 80, 000 and 325, 000 people will experience Long-COVID for at least 12 weeks, with as many as 170, 000 still experiencing long-COVID symptoms up to 12 months post infection (75). Our findings suggest that in October 2023, over 1 million people could be experiencing long-COVID symptoms.

A vaccine plus strategy, which includes increased access to testing, isolation, masks and safe indoor air, will mitigate the continued infection of Australians with SARS-COV-2 and help reduce the long-term burden of long-COVID.

Models of long-COVID projections can be used to test the impact of infection prevention and control strategies on future burden of long-COVID. We will continue to develop this work.

References

1. World Health Organization. At least 17 million people in the WHO European Region experienced long COVID in the first two years of the pandemic; millions may have to live with it for years to come. 2022. [cited 2022 November 9]. Available from: <https://www.who.int/europe/news/item/13-09-2022-at-least-17-million-people-in-the-who-european-region-experienced-long-covid-in-the-first-two-years-of-the-pandemic--millions-may-have-to-live-with-it-for-years-to-come>.
2. Arjun MC, Singh AK, Pal D, Das K, Gajjala A, Venkateshan M, et al. Prevalence, characteristics, and predictors of Long COVID among diagnosed cases of COVID-19. medRxiv. 2022:2022.01.04.21268536.
3. Munblit D, Nicholson TR, Needham DM, Seylanova N, Parr C, Chen J, et al. Studying the post-COVID-19 condition: research challenges, strategies, and importance of Core Outcome Set development. BMC Med. 2022;20(1):50.
4. Adler L, Gazit S, Pinto Y, Perez G, Mizrahi Reuveni M, Yehoshua I, et al. Long-COVID in patients with a history of mild or asymptomatic SARS-CoV-2 infection: a Nationwide Cohort Study. Scandinavian Journal of Primary Health Care. 2022:1-8.
5. Bull-Otterson L BS, Saydah S, Boehmer TK, Adjei S, Gray S, Harris AM. . Post-COVID Conditions Among Adult COVID-19 Survivors Aged 18-64 and ≥ 65 Years - United States, March 202- November 2021. Morbidity and Mortality Weekly Report (MMWR) 2022 71(713-717).
6. Lopez-Leon S, Wegman-Ostrosky T, Ayuzo del Valle NC, Perelman C, Sepulveda R, Rebolledo PA, et al. Long-COVID in children and adolescents: a systematic review and meta-analyses. Scientific Reports. 2022;12(1):9950.
7. Carvalho-Schneider C, Laurent E, Lemaigen A, Beaufils E, Bourbao-Tournois C, Laribi S, et al. Follow-up of adults with noncritical COVID-19 two months after symptom onset. Clin Microbiol Infect. 2021;27(2):258-63.
8. Carfi A, Bernabei R, Landi F, Group ftGAC-P-ACS. Persistent Symptoms in Patients After Acute COVID-19. JAMA. 2020;324(6):603-5.
9. Huang C, Huang L, Wang Y, Li X, Ren L, Gu X, et al. 6-month consequences of COVID-19 in patients discharged from hospital: A cohort study. The Lancet. 2021;397:220-32.
10. Perlis RH, Santillana M, Ognyanova K, Safarpour A, Lunz Trujillo K, Simonson MD, et al. Prevalence and Correlates of Long COVID Symptoms Among US Adults. JAMA Network Open. 2022;5(10):e2238804-e.
11. Ayoubkhani D, Khunti K, Nafilyan V, Maddox T, Humberstone B, Diamond I, et al. Post-covid syndrome in individuals admitted to hospital with covid-19: retrospective cohort study. BMJ. 2021;372:n693.
12. Donnelly JP, Wang XQ, Iwashyna TJ, Prescott HC. Readmission and Death After Initial Hospital Discharge Among Patients With COVID-19 in a Large Multihospital System. JAMA. 2021;325(3):304-6.
13. Hastie CE, Lowe DJ, McAuley A, Winter AJ, Mills NL, Black C, et al. Outcomes among confirmed cases and a matched comparison group in the Long-COVID in Scotland study. Nature Communications. 2022;13(1):5663.
14. Biddle N, Korda R. The experience of COVID-19 in Australia, including long-COVID: evidence from the COVID-19 Impact Monitoring Survey Series, August 2022: Centre for Social Research and Methods (ANU); 2022.
15. Subramanian A, Nirantharakumar K, Hughes S, Myles P, Williams T, Gokhale KM, et al. Symptoms and risk factors for long COVID in non-hospitalized adults. Nature Medicine. 2022;28(8):1706-14.
16. Thompson EJ, Williams DM, Walker AJ, Mitchell RE, Niedzwiedz CL, Yang TC, et al. Long COVID burden and risk factors in 10 UK longitudinal studies and electronic health records. Nature Communications. 2022;13(1):3528.
17. Rigoni M, Torri E, Nollo G, Donne LD, Rizzardo S, Lenzi L, et al. "Long COVID" results after hospitalization for SARS-CoV-2 infection. Scientific Reports. 2022;12(1):9581.

18. Goërtz YMJ, Van Herck M, Delbressine JM, Vaes AW, Meys R, Machado FVC, et al. Persistent symptoms 3 months after a SARS-CoV-2 infection: the post-COVID-19 syndrome? *ERJ Open Res.* 2020;6(4).
19. Blomberg B, Mohn KG-I, Brokstad KA, Zhou F, Linchausen DW, Hansen B-A, et al. Long COVID in a prospective cohort of home-isolated patients. *Nature medicine.* 2021;27(9):1607-13.
20. Huang Y, Pinto MD, Borelli JL, Asgari Mehrabadi M, Abraham HL, Dutt N, et al. COVID Symptoms, Symptom Clusters, and Predictors for Becoming a Long-Hauler Looking for Clarity in the Haze of the Pandemic. *Clin Nurs Res.* 2022;31(8):1390-8.
21. Global Burden of Disease Long COVID Collaborators. Estimated Global Proportions of Individuals With Persistent Fatigue, Cognitive, and Respiratory Symptom Clusters Following Symptomatic COVID-19 in 2020 and 2021. *JAMA.* 2022;328(16):1604-15.
22. Ayoubkhani D, Bermingham C, Pouwels KB, Glickman M, Nafilyan V, Zaccardi F, et al. Trajectory of long covid symptoms after covid-19 vaccination: community based cohort study. *Bmj.* 2022;377:e069676.
23. Chudzik M, Lewek J, Kapusta J, Banach M, Jankowski P, Bielecka-Dabrowa A. Predictors of Long COVID in Patients without Comorbidities: Data from the Polish Long-COVID Cardiovascular (PoLoCOV-CVD) Study. *J Clin Med.* 2022;11(17).
24. Cabrera Martimbianco AL, Pacheco RL, Bagattini Â M, Riera R. Frequency, signs and symptoms, and criteria adopted for long COVID-19: A systematic review. *Int J Clin Pract.* 2021;75(10):e14357.
25. Nasserie T, Hittle M, Goodman SN. Assessment of the Frequency and Variety of Persistent Symptoms Among Patients With COVID-19: A Systematic Review. *JAMA Network Open.* 2021;4(5):e2111417-e.
26. Rass V, Beer R, Schiefecker AJ, Kofler M, Lindner A, Mahlknecht P, et al. Neurological outcome and quality of life 3 months after COVID-19: A prospective observational cohort study. *Eur J Neurol.* 2021;28(10):3348-59.
27. Petersen MS, Kristiansen MF, Hanusson KD, Danielsen ME, B ÁS, Gaini S, et al. Long COVID in the Faroe Islands: A Longitudinal Study Among Nonhospitalized Patients. *Clin Infect Dis.* 2021;73(11):e4058-e63.
28. Logue JK, Franko NM, McCulloch DJ, McDonald D, Magedson A, Wolf CR, et al. Sequelae in Adults at 6 Months After COVID-19 Infection. *JAMA Network Open.* 2021;4(2):e210830-e.
29. Xiong Q, Xu M, Li J, Liu Y, Zhang J, Xu Y, et al. Clinical sequelae of COVID-19 survivors in Wuhan, China: a single-centre longitudinal study. *Clin Microbiol Infect.* 2021;27(1):89-95.
30. Zayet S, Zahra H, Royer PY, Tipirdamaz C, Mercier J, Gendrin V, et al. Post-COVID-19 Syndrome: Nine Months after SARS-CoV-2 Infection in a Cohort of 354 Patients: Data from the First Wave of COVID-19 in Nord Franche-Comté Hospital, France. *Microorganisms.* 2021;9(8).
31. Al-Aly Z, Bowe B, Xie Y. Long COVID after breakthrough SARS-CoV-2 infection. *Nature Medicine.* 2022;28(7):1461-7.
32. Bowe B, Xie Y, Al-Aly Z. Acute and postacute sequelae associated with SARS-CoV-2 reinfection. *Nature Medicine.* 2022.
33. Peter RS, Nieters A, Kräusslich HG, Brockmann SO, Göpel S, Kindle G, et al. Post-acute sequelae of covid-19 six to 12 months after infection: population based study. *Bmj.* 2022;379:e071050.
34. Bek LM, Berentschot JC, Heijenbrok-Kal MH, Huijts S, van Genderen ME, Vlakte JH, et al. Symptoms persisting after hospitalisation for COVID-19: 12 months interim results of the CO-FLOW study. *ERJ Open Research.* 2022;8(4):00355-2022.
35. Whitaker M, Elliott J, Chadeau-Hyam M, Riley S, Darzi A, Cooke G, et al. Persistent COVID-19 symptoms in a community study of 606,434 people in England. *Nature communications.* 2022;13(1):1957-.

36. Dryden M, Mudara C, Vika C, Blumberg L, Mayet N, Cohen C, et al. Post-COVID-19 condition 3 months after hospitalisation with SARS-CoV-2 in South Africa: a prospective cohort study. *The Lancet Global Health*. 2022;10(9):e1247-e56.
37. Chen C, Hauptert SR, Zimmermann L, Shi X, Fritsche LG, Mukherjee B. Global Prevalence of Post-Coronavirus Disease 2019 (COVID-19) Condition or Long COVID: A Meta-Analysis and Systematic Review. *J Infect Dis*. 2022;226(9):1593-607.
38. Robineau O, Zins M, Touvier M, Wiernik E, Lemogne C, de Lamballerie X, et al. Long-lasting Symptoms After an Acute COVID-19 Infection and Factors Associated With Their Resolution. *JAMA Network Open*. 2022;5(11):e2240985-e.
39. Al-Aly Z, Bowe B, Xie Y. Long Covid after Breakthrough COVID-19: the post-acute sequelae of breakthrough COVID-19. 2021.
40. Kids LCSaLC. How do COVID reinfections affect Long Covid? Results from an internet survey of people with Long Covid. 2022.
41. Xie Y, Choi T, Al-Aly Z. Nirmatrelvir and the Risk of Post-Acute Sequelae of COVID-19. *medRxiv*. 2022:2022.11.03.22281783.
42. Taquet M, Dercon Q, Luciano S, Geddes JR, Husain M, Harrison PJ. Incidence, co-occurrence, and evolution of long-COVID features: A 6-month retrospective cohort study of 273,618 survivors of COVID-19. *PLOS Medicine*. 2021;18(9):e1003773.
43. Borch L, Holm M, Knudsen M, Ellermann-Eriksen S, Hagstroem S. Long COVID symptoms and duration in SARS-CoV-2 positive children — a nationwide cohort study. *European Journal of Pediatrics*. 2022;181(4):1597-607.
44. Haddad A, Janda A, Renk H, Stich M, Frieh P, Kaier K, et al. Long COVID symptoms in exposed and infected children, adolescents and their parents one year after SARS-CoV-2 infection: A prospective observational cohort study. *eBioMedicine*. 2022;84.
45. Miller F, Nguyen DV, Navaratnam AMD, Shrotri M, Kovar J, Hayward AC, et al. Prevalence and Characteristics of Persistent Symptoms in Children During the COVID-19 Pandemic: Evidence From a Household Cohort Study in England and Wales. *Pediatr Infect Dis J*. 2022;41(12).
46. Osmanov IM, Spiridonova E, Bobkova P, Gamirova A, Shikhaleva A, Andreeva M, et al. Risk factors for post-COVID-19 condition in previously hospitalised children using the ISARIC Global follow-up protocol: a prospective cohort study. *European Respiratory Journal*. 2022;59(2).
47. Say D, Crawford N, McNab S, Wurzel D, Steer A, Tosif S. Post-acute COVID-19 outcomes in children with mild and asymptomatic disease. *The Lancet Child & Adolescent Health*. 2021;5(6):e22-e3.
48. Smane L, Stars I, Pucuka Z, Roge I, Pavare J. Persistent clinical features in paediatric patients after SARS-CoV-2 virological recovery: a retrospective population-based cohort study from a single centre in Latvia. *BMJ Paediatrics Open*. 2020;4(1).
49. Buonsenso D, Munblit D, De Rose C, Sinatti D, Ricchiuto A, Carfi A, et al. Preliminary evidence on long COVID in children. *Acta Paediatrica (Oslo, Norway: 1992)*. 2021;110(7):2208.
50. Molteni E, Sudre CH, Canas LS, Bhopal SS, Hughes RC, Antonelli M, et al. Illness duration and symptom profile in symptomatic UK school-aged children tested for SARS-CoV-2. *Lancet Child Adolesc Health*. 2021;5(10):708-18.
51. Stephenson T, Stephenson T, Pereira SP, Shafran R, De Stavola B, Rojas N, et al. Long COVID—the physical and mental health of children and non-hospitalised young people 3 months after SARS-CoV-2 infection; a national matched cohort study (The CLoCk) Study. 2021.
52. Sterky E, Olsson-Åkefeldt S, Hertting O, Herlenius E, Alfven T, Ryd Rinder M, et al. Persistent symptoms in Swedish children after hospitalisation due to COVID-19. *Acta Paediatr*. 2021;110(9):2578-80.
53. Behnood SA, Shafran R, Bennett SD, Zhang AXD, O'Mahoney LL, Stephenson TJ, et al. Persistent symptoms following SARS-CoV-2 infection amongst children and young people: A meta-analysis of controlled and uncontrolled studies. *Journal of Infection*. 2022;84(2):158-70.

54. Roge I, Smane L, Kivite-Urtane A, Pucuka Z, Racko I, Klavina L, et al. Comparison of Persistent Symptoms After COVID-19 and Other Non-SARS-CoV-2 Infections in Children. *Frontiers in Pediatrics*. 2021;9.
55. Asadi-Pooya AA, Nemati H, Shahisavandi M, Akbari A, Emami A, Lotfi M, et al. Long COVID in children and adolescents. *World Journal of Pediatrics*. 2021;17(5):495-9.
56. Fainardi V, Meoli A, Chiopris G, Motta M, Skenderaj K, Grandinetti R, et al. Long COVID in Children and Adolescents. *Life*. 2022;12(2):285.
57. Kikkenborg Berg S, Palm P, Nygaard U, Bundgaard H, Petersen MNS, Rosenkilde S, et al. Long COVID symptoms in SARS-CoV-2-positive children aged 0–14 years and matched controls in Denmark (LongCOVIDKidsDK): a national, cross-sectional study. *The Lancet Child & Adolescent Health*. 2022;6(9):614-23.
58. Collaborators GBoDLC. Estimated Global Proportions of Individuals With Persistent Fatigue, Cognitive, and Respiratory Symptom Clusters Following Symptomatic COVID-19 in 2020 and 2021. *JAMA*. 2022;328(16):1604-15.
59. Azzolini E, Levi R, Sarti R, Pozzi C, Mollura M, Mantovani A, et al. Association Between BNT162b2 Vaccination and Long COVID After Infections Not Requiring Hospitalization in Health Care Workers. *JAMA*. 2022;328(7):676-8.
60. Australian Government Department of Health and Aged Care. COVID-19 Vaccine Roll-out. 10 November 2022. [Cited 2022 November 18]. Available from: <https://www.health.gov.au/sites/default/files/documents/2022/11/covid-19-vaccine-rollout-update-10-november-2022.pdf>.
61. Australian Government Department of Health and Aged Care. ATAGI statement on recommendations on a winter booster dose of COVID-19 vaccine. 25 March 2022. [Cited 2022 November 18]. Available from: <https://www.health.gov.au/news/atagi-statement-on-recommendations-on-a-winter-booster-dose-of-covid-19-vaccine>.
62. Australian Government Department of Health and Aged Care. ATAGI updated recommendations for a winter dose of COVID-19 vaccine, 7 July 2022. [Cited 2022 November 18]. Available from: <https://www.health.gov.au/news/atagi-updated-recommendations-for-a-winter-dose-of-covid-19-vaccine>.
63. Australian Government Department of Health and Aged Care. ATAGI update on boosters following COVID-19 meeting on 11 November 2022. 15 November 2022. [Cited 2022 November 18]. Available from: <https://www.health.gov.au/news/atagi-update-on-boosters-following-covid-19-meeting-on-11-november-2022>.
64. Australian Government Department of Health and Aged Care. Clinical recommendations for COVID-19 vaccines. 24 October 2022. [Cited 2022 November 18]. Available from: <https://www.health.gov.au/initiatives-and-programs/covid-19-vaccines/advice-for-providers/clinical-guidance/clinical-recommendations#:~:text=their%20second%20dose,-Booster%20dose%20recommendations,3%20or%20more%20months%20ago>.
65. Brüssow H, Timmis K. COVID-19: long covid and its societal consequences. *Environmental Microbiology*. 2021;23(8):4077-91.
66. CIPD. Nearly half of employers have staff who have experienced long COVID in the last year, new research finds. 2022. [Cited 2022 November 18]. Available from: <https://www.cipd.co.uk/about/media/press/08022long-covid#gref>.
67. Australian Healthcare & Hospitals Association. Long term health consequences of COVID-19: can value-based health care provide a way forward. 2021. [cited on 2022 November 16.].
68. [Internet]. OWiD. Coronavirus (COVID-19) Cases. 2022. [Cited 2022 November 15]. Available from: <https://ourworldindata.org/covid-cases#cases-of-covid-19-background>.
69. Our World in Data [internet]. How epidemiological models of COVID-19 help us estimate the true number of infections. 2022. [Cited 2022 November 15]. Available from: <https://ourworldindata.org/covid-models>.

70. Kirby Institute [Internet]. Serosurveillance for SARS-CoV-2 infection to inform public health responses. 2022. [Cited 2022 November 15]. Available from: <https://kirby.unsw.edu.au/project/serosurveillance-sars-cov-2-infection-inform-public-health-responses>.
71. PAEDS-Paediatric Active Enhanced Disease Surveillance. Paediatric SARS-CoV-2 serosurvey 2022, Australia Summary report [Internet]. 2022. [Cited 2022 November 15]. Available from: https://paeds.org.au/sites/default/files/2022-11/PAEDSNCIRS_COVID-19PaediatricSerosurvey2022Report_3-11-2022_Final.pdf.
72. Magen O, Waxman JG, Makov-Assif M, Vered R, Dicker D, Hernán MA, et al. Fourth Dose of BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Setting. *New England Journal of Medicine*. 2022;386(17):1603-14.
73. World Health Organization. WHO Coronavirus (COVID-19) Dashboard. 2022. [cited on 2022 November 18.]. Available from: <https://covid19.who.int/table>.
74. Australian Institute of Health and Welfare. International health data comparisons. 2022. [cited 2022 November 11]. Available from: <https://www.aihw.gov.au/reports/international-comparisons/international-health-data-comparisons#How>.
75. Martin Henscher & Mary Rose Angeles. Potential scale of Long COVID cases from the Omicron wave in Australia: Summer 2021-2022. 2022. [Cited 2022 November 18]. Available from: <https://iht.deakin.edu.au/2022/11/new-modelling-shows-the-scale-and-impact-of-long-covid-across-australia/>.