Population Immunity

Subjects: Health Care Sciences & Services

Contributor: Ursino Pacheco-García , Jeanet Serafín-López

Herd immunity is a population condition where the pathogen dispersion between the community members is difficult or impossible because when an infected individual appears, the individuals surrounding her/him are immune against the pathogen, so they do not get infected and do not transmit the pathogen to other susceptible individuals.

LAVs SARS-CoV-2 attenuated virus herd immunity

1. Introduction

In the face of the appearance in China in December 2019 of a new human infectious disease called COVID-19, caused by the SARS-CoV-2 coronavirus [1][2][3][4][5], countries implemented governmental measures to control the virus dispersion among the population. The virus showed a high infection frequency in humans [6][7], and from the beginning, there was great difficulty in containing its spread through confinement [8]. Moreover, there was a high frequency of severe and lethal cases in elderly persons, mainly those with comorbidities such as diabetes and hypertension [9]. SARS-CoV-2 coronavirus propagated to several countries in February and March 2020 [10][11][12][13], and in the same year, the WHO declared a pandemic on March 11 [14].

At the start of the SARS-CoV-2 world dispersion, some governmental leaders (in countries from northern Europe, for example) proposed that its propagation could be controlled by allowing the free infection of individuals, which would induce protection by antibodies and cellular immunity in a high proportion of the population, thus achieving herd immunity (HI). That would lead to the consequent reduction or even elimination of the infectious agent [15]. Very soon, the proposition was strongly challenged [16][17][18] because achieving collective immunity through the infection dispersion could have a high cost on human lives and health complications caused by COVID-19 in elderly persons, mainly in those with comorbidities [1][9]. It was observed that although the percentage of lethality in the population was low in general, the high incidence of infection raised the absolute number of severe and lethal cases [19][20][21] so, as a better option, it was decided to control propagation through the containment of human activity to reduce the contact between individuals. Social mobility was restricted to allow only the circulation of persons dedicated to essential activities [20][21][22][23], waiting for the identification of effective antiviral drugs to treat infected individuals and the approval of efficient vaccines to achieve HI through massive vaccination [24]. In several countries, quarantine was strictly enforced, attaining a significant decrease in the number of cases during the first wave of infections [24][25][26]. Nevertheless, a few months after the pandemic's beginning and with a still high incidence of infections and high numbers of deaths, the gradual return to essential and non-essential human activities was allowed in most countries. The decision was taken due to the population's demand to restart their

economic activities, which would be further affected by a quarantine extension [27][28][29][30][31][32]. After human activities were restarted, contagion increased again in several countries, with several waves of cases at different times and places [31][32]. For this reason, in the following months, there was a partial tolerance for the realization of economic activities, combined with partial social distancing, personal hygiene and other protection measures [33][34]. In December 2020, the massive application of different types of non-proliferative vaccines started in several countries [35][36]. Although in many developed and some developing countries, several booster shots have been administered, there are underdeveloped countries where vaccination has been delayed or is still very limited, mainly due to economic limitations, which prevented them from accessing vaccines since the first days after their approval [37][38][39][40][41]. There are still many developing countries where a sufficient proportion of the protected population has not been reached to be near the herd immunity threshold (HIT) against SARS-CoV-2 [39][40][41]. The risk of massive infections in several countries is latent, as well as the risk of the appearance and propagation of more dangerous and contagious mutant strains if the virus is still propagating in populations with low immunization rates [41]. On the other hand, in several countries, a proportion of the population opposes vaccination [42][43], which hampers the achievement of the herd immunity threshold, in addition to the fact that in many developing and underdeveloped countries, child vaccination is still low or inexistent [44][45].

After the massive application of vaccines, severe cases and mortality decreased sharply, as well as recovery time for the anew infected and the re-infected. Although there is a high proportion of immunized persons, the individual neutralizing antibody levels decline after some time, so epidemic outbreaks keep appearing due to new virus variants, some of which have been dispersed globally and others more locally. Nevertheless, as vaccinated individuals and those that recovered from infection maintain a certain degree of immunity, if they are re-infected, their symptoms are less severe, and they show lower mortality [46][47][48]. All of the above make necessary the application of boosters to help maintain protective immunity levels in the population in the face of the dispersion of new variants [49][50][51].

2. Population Immunity

Individual immunity against a pathogen is a state in which the different components of the immunological system are prepared to protect her/him from this microorganism by controlling or eliminating it in case of infection [52][53][54]. In a given population, there is a certain proportion of individuals with immunity against one particular pathogen. If a pathogen is new for a population, the proportion of immune individuals is probably zero, and this population is likely to be highly susceptible to becoming infected by this new pathogen. Herd immunity is a population condition where the pathogen dispersion between the community members is difficult or impossible because when an infected individual appears, the individuals surrounding her/him are immune against the pathogen, so they do not get infected and do not transmit the pathogen to other susceptible individuals. Besides, in a population with a high proportion of immune individuals, the probability of an encounter between an infected and a susceptible individual is very low [55][56][57][58][59][60][61][62]. Herd immunity threshold (HIT) refers to the fraction of the population required to be immune against an infectious pathogen to prevent its dispersion. A population has reached herd immunity when it has a proportion of immune individuals against a particular pathogen equal to or above the HIT [62][63]. To

calculate the proportion of the immune population required to reach the HIT, one must consider the pathogen dispersion capacity, which is given by the reproduction number R_0, which indicates the average number of non-immune individuals whom a sick individual infects [55][56][57][58][59][60][61][62][63][64][65][66][67][68]. The fraction of the population required to reach HI in populations with a homogeneous immune response elicited by highly effective vaccines is calculated by the formula $1 - 1/R_0$. Nevertheless, the HIT can be calculated more precisely by considering several population factors and vaccine effectiveness [52][60][64]. It is generally considered that 70% percent of immune individuals against a particular pathogen in a population confers HI [52][58][65][66][67][68][69][70][71][72][73][74]. A similar percentage has been considered necessary for the SARS-CoV-2 case considering an $R_0 = 3$ and a HIT = 67 [58][65][66][67][68][69][70][71][72][73]. This percentage might vary between countries or regions [67][74][75]. Immunization against SARS-CoV-2 reduces susceptibility but does not totally protect against infection or reinfection, so it is estimated that the required HIT might be higher, reaching 95% for some populations [52][59][60][63][64][66][67][71][73][74].

A population acquires immunity and reaches the HIT in three ways: (a) through the contagion of individuals with the wild-type strain. The individuals develop the disease with different symptomatology degrees and develop protective immunity, (b) through vaccination with different vaccine types, including inactivated vaccines, non-proliferative viral vector vaccines, and live-attenuated vaccines. (c) through the combination of natural dispersion and massive vaccination [75].

References

1. Chen, G.; Wu, D.; Guo, W.; Cao, Y.; Huang, D.; Wang, H.; Wang, T.; Zhang, X.; Chen, H.; Yu, H.; et al. Clinical and immunological features of severe and moderate coronavirus disease 2019. J. Clin. Investig. 2020, 130, 2620–2629.
2. Zhu, N.; Zhang, D.; Wang, W.; Li, X.; Yang, B.; Song, J.; Zhao, X.; Huang, B.; Shi, W.; Lu, R.; et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. N. Engl. J. Med. 2020, 382, 727–733.
3. Coronaviridae Study Group of the International Committee on Taxonomy of Viruses. The species Severe acute respiratory syndrome related coronavirus: Classifying 2019-nCoV and naming it SARS-CoV-2. Nat. Microbiol. 2020, 5, 536–544.
4. Wan, Y.; Shang, J.; Graham, R.; Baric, R.S.; Li, F. Receptor Recognition by the Novel Coronavirus from Wuhan: An Analysis Based on Decade-Long Structural Studies of SARS Coronavirus. J. Virol. 2020, 94, e00127-20.
5. Zhou, P.; Yang, X.L.; Wang, X.G.; Hu, B.; Zhang, L.; Zhang, W.; Si, H.R.; Zhu, Y.; Li, B.; Huang, C.L.; et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 2020, 579, 270–273.

6. Laer, S.A.; Grantz, K.H.; Bi, Q.; Jones, F.K.; Zheng, Q.; Meredith, H.R.; Azman, A.S.; Reich, N.G.; Lessler, J. The Incubation Period of Coronavirus Disease 2019 (COVID-19) from Publicly Reported Confirmed Cases: Estimation and Application. Ann. Intern. Med. 2020, 172, 577–582.
7. Li, R.; Pei, S.; Chen, B.; Song, Y.; Zhang, T.; Yang, W.; Shaman, J. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). Science 2020, 368, 489–493.
8. Thompson, R.N. Epidemiological models are important tools for guiding COVID-19 interventions. BMC Med. 2020, 18, 152.
9. Chen, N.; Zhou, M.; Dong, X.; Qu, J.; Gong, F.; Han, Y.; Qiu, Y.; Wang, J.; Liu, Y.; Wei, Y.; et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: A descriptive study. Lancet 2020, 395, 507–513.
10. Holshue, M.L.; DeBolt, C.; Lindquist, S.; Lofy, K.H.; Wiesman, J.; Bruce, H.; Spitters, C.; Ericson, K.; Wilkerson, S.; Tural, A.; et al. First Case of 2019 Novel Coronavirus in the United States. N. Engl. J. Med. 2020, 382, 929–936.
11. Ali, H.; Hossain, M.F.; Hasan, M.M.; Abujar, S. COVID-19 Dataset: Worldwide spread log including countries first case and first death. Data Brief 2020, 32, 106173.
12. Singh, S.K. COVID-19: A master stroke of Nature. AIMS Public Health 2020, 7, 393–402.
13. Kupferschmidt, K.; Cohen, J. Will novel virus go pandemic or be contained? Science 2020, 367, 610–611.
14. Cucinotta, D.; Vanelli, M. WHO Declares COVID-19 a Pandemic. Acta Bio-Med. Atenei Parm. 2020, 91, 157–160.
15. Linka, K.; Peirlinck, M.; Kuhl, E. The reproduction number of COVID-19 and its correlation with public health interventions. Comput. Mech. 2020, 66, 1035–1050.
16. Brett, T.S.; Rohani, P. Transmission dynamics reveal the impracticality of COVID-19 herd immunity strategies. Proc. Natl. Acad. Sci. USA 2020, 117, 25897–25903.
17. Medley, G.F. Herd immunity confusion. Lancet 2020, 396, 1634–1635.
18. Aschwanden, C. The false promise of herd immunity for COVID-19. Nature 2020, 587, 26–28.
19. Khalil, A.; Al-Handawi, K.; Mohsen, Z.; AbdelNour, A.; Feghali, R.; Chamseddine, I.; Kokkolaras, M. Weekly Nowcasting of New COVID-19 Cases Using Past Viral Load Measurements. Viruses 2022, 14, 1414.
20. DeSalvo, K.; Hughes, B.; Bassett, M.; Benjamin, G.; Fraser, M.; Galea, S.; Gracia, J.N. Public Health COVID-19 Impact Assessment: Lessons Learned and Compelling Needs. NAM Perspect. 2021, 2021, 10.31478/202104c.

21. Karia, R.; Gupta, I.; Khandait, H.; Yadav, A.; Yadav, A. COVID-19 and Its Modes of Transmission. SN Compr. Clin. Med. 2020, 2, 1798–1801.
22. Schmidt, B.; Davids, E.L.; Malinga, T. Quarantine alone or in combination with other public health measures to control COVID-19: A rapid Cochrane review. South Afr. Med. J. 2020, 110, 476–477.
23. Nussbaumer-Streit, B.; Mayr, V.; Dobrescu, A.I.; Chapman, A.; Persad, E.; Klerings, I.; Wagner, G.; Siebert, U.; Ledinger, D.; Zachariah, C.; et al. Quarantine alone or in combination with other public health measures to control COVID-19: A rapid review. Cochrane Database Syst. Rev. 2020, 9, CD013574.
24. Gumel, A.B.; Iboi, E.A.; Ngonghala, C.N.; Ngwa, G.A. Toward Achieving a Vaccine-Derived Herd Immunity Threshold for COVID-19 in the U. S. Front. Public Health 2021, 9, 709369.
25. Talic, S.; Shah, S.; Wild, H.; Gasevic, D.; Maharaj, A.; Ademi, Z.; Li, X.; Xu, W.; Mesa-Eguiagaray, I.; Rostron, J.; et al. Effectiveness of public health measures in reducing the incidence of COVID-19, SARS-CoV-2 transmission, and COVID-19 mortality: Systematic review and meta-analysis. BMJ (Clin. Res. Ed.) 2021, 375, e068302.
26. Sanchez, J.N.; Reyes, G.A.; Martínez-López, B.; Johnson, C.K. Impact of social distancing on early SARS-CoV-2 transmission in the United States. Zoonoses Public Health 2022, 69, 746–756.
27. Nicola, M.; Alsafi, Z.; Sohrabi, C.; Kerwan, A.; Al-Jabir, A.; Iosifidis, C.; Agha, M.; Agha, R. The socio-economic implications of the coronavirus pandemic (COVID-19): A review. Int. J. Surg. 2020, 78, 185–193.
28. Bonaccorsi, G.; Pierri, F.; Cinelli, M.; Flori, A.; Galeazzi, A.; Porcelli, F.; Schmidt, A.L.; Valensise, C.M.; Scala, A.; Quattrociocchi, W.; et al. Economic and social consequences of human mobility restrictions under COVID-19. Proc. Natl. Acad. Sci. USA 2020, 117, 15530–15535.
29. Kamar, A.; Maalouf, N.; Hitti, E.; ElEid, G.; Isma'eel, H.; Elhajj, I.H. Challenge of forecasting demand of medical resources and supplies during a pandemic: A comparative evaluation of three surge calculators for COVID-19. Epidemiol. Infect. 2021, 149, e51.
30. Maciel, E.L.; Oliveira, W.K.; Siqueira, P.C.; Croda, J. Are we near the end of the pandemic? Rev. Soc. Bras. Med. Trop. 2022, 55, e02332022.
31. Mulugeta, T.; Tadesse, E.; Shegute, T.; Desta, T.T. COVID-19: Socio-economic impacts and challenges in the working group. Heliyon 2021, 7, e07307.
32. Zhao, L.; Rasoulinezhad, E.; Sarker, T.; Taghizadeh-Hesary, F. Effects of COVID-19 on Global Financial Markets: Evidence from Qualitative Research for Developed and Developing Economies. Eur. J. Dev. Res. 2022, 35, 148–166.
33. Chu, D.K.; Akl, E.A.; Duda, S.; Solo, K.; Yaacoub, S.; Schünemann, H.J. COVID-19 Systematic Urgent Review Group Effort (SURGE) study authors Physical distancing, facemasks and eye

protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: A systematic review and meta-analysis. Lancet 2020, 395, 1973–1987.

34. Lyu, W.; Wehby, G.L. Community Use of Face Masks And COVID-19: Evidence from a Natural Experiment of State Mandates in the US. Health Aff. (Proj. Hope) 2020, 39, 1419–1425.
35. Hodgson, S.H.; Mansatta, K.; Mallett, G.; Harris, V.; Emary, K.R.W.; Pollard, A.J. What defines an efficacious COVID-19 vaccine? A review of the challenges assessing the clinical efficacy of vaccines against SARS-CoV-2. Lancet Infect. Dis. 2021, 21, e26–e35.
36. Matrajt, L.; Eaton, J.; Leung, T.; Brown, E.R. Vaccine optimization for COVID-19: Who to vaccinate first? Sci. Adv. 2021, 7, eabf1374.
37. Binagwaho, A.; Mathewos, K.; Davis, S. Time for the ethical management of COVID-19 vaccines. Lancet Glob. Health 2021, 9, e1169–e1171.
38. Kavanagh, M.M.; Gostin, L.O.; Sunder, M. Sharing Technology and Vaccine Doses to Address Global Vaccine Inequity and End the COVID-19 Pandemic. JAMA 2021, 326, 219–220.
39. Ariyo, O.E.; Oladipo, E.K.; Osasona, O.G.; Obe, O.; Olomojobi, F. COVID-19 vaccines and vaccination: How prepared is Africa? Pan Afr. Med. J. 2021, 39, 107.
40. Massinga Loembé, M.; Nkengasong, J.N. COVID-19 vaccine access in Africa: Global distribution, vaccine platforms, and challenges ahead. Immunity 2021, 54, 1353–1362.
41. Lucero-Prisno, D.E.; Ogunkola, I.O., 3rd; Esu, E.B.; Adebisi, Y.A.; Lin, X.; Li, H. Can Africa achieve herd immunity? Glob. Health Res. Policy 2021, 6, 46.
42. Parthasarathi, A.; Puvvada, R.K.; Shankar, M.; Siddaiah, J.B.; Ganguly, K.; Upadhyay, S.; Mahesh, P.A. Willingness to Accept the COVID-19 Vaccine and Related Factors among Indian Adults: A Cross-Sectional Study. Vaccines 2022, 10, 1095.
43. Cag, Y.; AlMadadha, M.E.; Ankarali, H.; Cag, Y.; Demir Onder, K.; Seremet-Keskin, A.; Kizilates, F.; Čivljak, R.; Shehata, G.; Alay, H.; et al. Vaccine hesitancy and refusal among parents: An international IID-IRI survey. J. Infect. Dev. Ctries. 2022, 1 6, 1081–1088.
44. Cohen, R.; Ashman, M.; Taha, M.K.; Varon, E.; Angoulvant, F.; Levy, C.; Rybak, A.; Ouldali, N.; Guiso, N.; Grimprel, E. Pediatric Infectious Disease Group (GPIP) position paper on the immune debt of the COVID-19 pandemic in childhood, how can we fill the immunity gap? Infect. Dis. Now 2021, 51, 418–423.
45. Obohwemu, K.; Christie-deJong, F.; Ling, J. Parental childhood vaccine hesitancy and predicting uptake of vaccinations: A systematic review. Prim. Health Care Res. Dev. 2022, 23, e68.
46. Pilz, S.; Theiler-Schwetz, V.; Trummer, C.; Krause, R.; Ioannidis, J.P.A. SARS-CoV-2 reinfections: Overview of efficacy and duration of natural and hybrid immunity. Environ. Res. 2022, 209, 112911.

47. Abu-Raddad, L.J.; Chemaitelly, H.; Bertollini, R.; National Study Group for COVID-19. Epidemiology Severity of SARS-CoV-2 Reinfections as Compared with Primary Infections. N. Engl. J. Med. 2021, 385, 2487–2489.
48. Cohen, J.I.; Burbelo, P.D. Reinfection With SARS-CoV-2: Implications for Vaccines. Clin. Infect. Dis. Off. Publ. Infect. Dis. Soc. Am. 2021, 73, e4223–e4228.
49. Tao, K.; Tzou, P.L.; Nouhin, J.; Gupta, R.K.; de Oliveira, T.; Kosakovsky Pond, S.L.; Fera, D.; Shafer, R.W. The biological and clinical significance of emerging SARS-CoV-2 variants. Nat. Rev. Genet. 2021, 22, 757–773.
50. Choi, J.Y.; Smith, D.M. SARS-CoV-2 Variants of Concern. Yonsei Med. J. 2021, 62, 961–968.
51. Araf, Y.; Akter, F.; Tang, Y.D.; Fatemi, R.; Parvez, M.S.A.; Zheng, C.; Hossain, M.G. Omicron variant of SARS-CoV-2: Genomics, transmissibility, and responses to current COVID-19 vaccines. J. Med. Virol. 2022, 94, 1825–1832.
52. Bach, J.F.; Berche, P.; Chatenoud, L.; Costagliola, D.; Valleron, A.J. COVID-19: Individual and herd immunity. Comptesren Dus Biol. 2021, 344, 7–18.
53. Carrillo, J.; Izquierdo-Useros, N.; Ávila-Nieto, C.; Pradenas, E.; Clotet, B.; Blanco, J. Humoral immune responses and neutralizing antibodies against SARS-CoV-2; implications in pathogenesis and protective immunity. Biochem. Biophys. Res. Commun. 2021, 538, 187–191.
54. Silva, M.J.A.; Ribeiro, L.R.; Lima, K.V.B.; Lima, L.N.G.C. Adaptive immunity to SARS-CoV-2 infection: A systematic review. Front. Immunol. 2022, 13, 1001198.
55. Fox, J.P.; Elveback, L.; Scott, W.; Gatewood, L.; Ackerman, E. Herd immunity: Basic concept and relevance to public health immunization practices. Am. J. Epidemiol. 1995, 141, 186–187.
56. Fine, P.E. Herd immunity: History, theory, practice. Epidemiol. Rev. 1993, 15, 265–302.
57. Randolph, H.E.; Barreiro, L.B. Herd Immunity: Understanding COVID-19. Immunity 2020, 52, 737–741.
58. Kadkhoda, K. Herd Immunity to COVID-19. Am. J. Clin. Pathol. 2021, 155, 471–472.
59. Britton, T.; Ball, F.; Trapman, P. A mathematical model reveals the influence of population heterogeneity on herd immunity to SARS-CoV-2. Science 2020, 369, 846–849.
60. Fontanet, A.; Cauchemez, S. COVID-19 herd immunity: Where are we? Nat. Rev. Immunol. 2020, 20, 583–584.
61. Xia, Y.; Zhong, L.; Tan, J.; Zhang, Z.; Lyu, J.; Chen, Y.; Zhao, A.; Huang, L.; Long, Z.; Liu, N.N.; et al. How to Understand “Herd Immunity” in COVID-19 Pandemic. Front. Cell Dev. Biol. 2020, 8, 547314.

62. Dong, M.; He, F.; Deng, Y. How to Understand Herd Immunity in the Context of COVID-19. Viral Immunol. 2021, 34, 174–181.
63. Elbasha, E.H.; Gumel, A.B. Vaccination and herd immunity thresholds in heterogeneous populations. J. Math. Biol. 2021, 83, 73.
64. Neagu, M. The bumpy road to achieve herd immunity in COVID-19. J. Immunoass. Immunochem. 2020, 41, 928–945.
65. Jones, D.; Helmreich, S. A history of herd immunity. Lancet 2020, 396, 810–811.
66. Kwok, K.O.; Lai, F.; Wei, W.I.; Wong, S.Y.S.; Tang, J.W.T. Herd immunity—Estimating the level required to halt the COVID-19 epidemics in affected countries. J. Infect. 2020, 80, e32–e33.
67. Plans-Rubió, P. Percentages of Vaccination Coverage Required to Establish Herd Immunity against SARS-CoV-2. Vaccines 2022, 10, 736.
68. Zhao, S.; Cao, P.; Gao, D.; Zhuang, Z.; Cai, Y.; Ran, J.; Chong, M.K.C.; Wang, K.; Lou, Y.; Wang, W.; et al. Serial interval in determining the estimation of reproduction number of the novel coronavirus disease (COVID-19) during the early outbreak. J. Travel Med. 2020, 27, taaa033.
69. Liu, Y.; Gayle, A.A.; Wilder-Smith, A.; Rocklöv, J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. J. Travel Med. 2020, 27, taaa021.
70. Papachristodoulou, E.; Kakoullis, L.; Parperis, K.; Panos, G. Long-term and herd immunity against SARS-CoV-2: Implications from current and past knowledge. Pathog. Dis. 2020, 78, ftaa025.
71. Gomes, M.G.M.; Ferreira, M.U.; Corder, R.M.; King, J.G.; Souto-Maior, C.; Penha-Gonçalves, C.; Gonçalves, G.; Chikina, M.; Pegden, W.; Aguas, R. Individual variation in susceptibility or exposure to SARS-CoV-2 lowers the herd immunity threshold. J. Theor. Biol. 2022, 540, 111063.
72. Canals, L.M. Review of the concept of herd immunity, in the context of COVID-19 epidemic and the development of vaccines. Rev. Chil. Infectol. Organo Soc. Chil. Infectol. 2021, 38, 495–499.
73. MacIntyre, C.R.; Costantino, V.; Trent, M. Modelling of COVID-19 vaccination strategies and herd immunity, in scenarios of limited and full vaccines upply in NSW, Australia. Vaccine 2022, 40, 2506–2513.
74. Montalbán, A.; Corder, R.M.; Gomes, M.G.M. Herd immunity under individual variation and reinfection. J. Math. Biol. 2022, 85, 2.
75. Lipsitch, M.; Grad, Y.H.; Sette, A.; Crotty, S. Cross-reactive memory T cells and herd immunity to SARS-CoV-2. Nat. Ereviews Immunol. 2020, 20, 709–713.