http://dx.doi.org/10.2106/JBJS.20.01191


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## APPENDIX I

Mathematical Explanation of the Basic ($R_0$) and Effective ($R_e$) Reproductive Number

For SARS-CoV-2 $R_0$ has been estimated to be between 2 and 3[1], however values calculated range from 2.0 to 5.7[2]. These differences arise because $R_0$ values depend on the pathogen, the population studied, and the modelling methods used[3, 4]. Perhaps the greatest variability is conferred by transmission dynamics which are influenced by characteristics such as population structure, population density, and differences in contact rates across demographic groups and the number of pathogenic particles needed to infect[5]. Factors making the rate of transmission heterogeneous, such as spatial (e.g. social distancing), genetic, age-related, and behavioral diversity, can interrupt the chain of transmission and cause substantial variations in $R_0$. These variations can alter both the theoretical and observed spread of the pathogen[5]. Modelling assumptions (e.g. the infectiousness of the pathogen, the rate of disappearance of cases by recovery or death, and the intensity of surveillance) as well as the model itself can also have a large effect on variability[2, 6].

$R_e$ is calculated by multiplying $R_0$ by the proportion of individuals within the population who can still be infected; $R_e = R_0 \times (1 - P)$, where P is the proportion of the population who are immune at that time (Fig. 4). For the infection to propagate through a population $R_e$ must be $\geq 1$ (i.e. each infected person needs to infect at least one other person). Even when $R_e$ is only slightly lower than 1, the disease outbreak will end if given enough time. The lower an $R_e$ is for an outbreak the more quickly it will end[6].

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# APPENDIX II

## Herd Immunity

Herd immunity starts to take effect in infectious diseases when the herd immunity threshold ($P_{crit}$) is reached. $P_{crit}$ is the minimal proportion of the population that needs to be immune to achieve herd immunity for the entire group. This is calculated by the equation: $P_{crit} = 1-1/R_0$, represented by the curve found in Figure 5. Once the percentage of the population who is immune exceeds $P_{crit}$ then $R_e$ will fall below 1 and the infection incidence will decline independent of other factors[1]. The differences in calculated $R_0$ (see Appendix I) directly result in the various published $P_{crit}$ values. For SARS-CoV-2, if we use the consensus $R_0$ values of 2 to 3[2-6], then the herd immunity threshold would be calculated as follows:

$$\text{If } R_0=2 \text{ then } P_{crit}=1-½ \text{ or } 50\%$$

$$\text{If } R_0=3 \text{ then } P_{crit}=1-⅓ \text{ or } 66.7\%$$

This would mean that one-half to two-thirds of the population would need to become immune, either through vaccination or through infection with SARS-CoV-2, for us to bring $R_e$ below 1 and to start to see the effects of herd immunity on COVID-19 (Fig. 6).

Most recently, the U.S. population has been estimated at just over 328 million individuals. Estimates for the number of citizens with confirmed cases of COVID-19 is 1.5 million (0.45% of the population). Of these 100,000 are deceased[7]. Assuming that all survivors have generated an effective immune response from their illness, just over 1.4 million would have natural immunity. If this exposure estimate and immune response is correct we would need to vaccinate at least 163.25 to 218.75 million people in this country to reach $P_{crit}$.

Achieving herd immunity is important because we do not have curative treatments for COVID-19 at this time. Establishment of herd immunity, either through survival of infection and development of an immune response with or without an effective vaccination program, are the only ways COVID-19 can be eliminated as a pandemic, epidemic or endemic disease. The effect on a successful vaccination program in achieving this has been shown with other infectious diseases such as diphtheria. (Fig. 7). Through establishment of herd immunity we will be able to move away from using social distancing and return to interactions that we consider more normal[8]. Immunization programs that generate immunity below the level necessary for disease elimination are still valuable as they reduce the number of cases of infection[9].

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