High population densities catalyze the spread of COVID-19

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The control of the COVID-19 epidemic is in many locations moving from a public-health strategy of containment to mitigation.[1] A main control-strategy of COVID-19 is contact tracing. Its effectiveness depends on the pre-symptomatic and asymptomatic patterns of the disease. With 100% symptomatic cases, an R0 of 1.5 could be controlled with 50% of the contacts traced. With an R0 of 3.5, 90% is required.[2] With pre-symptomatic and potential asymptomatic transmission, the effectiveness of contact tracing is reduced further.[2] In Italy, for example, only one out of four cases is identified.[3] Thus, even for a low R0 and no pre-symptomatic transmission, contact tracing will on its own not be able to contain the outbreak. In addition to isolation of ill persons, contact tracing and quarantining of all their contacts, to reduce community spread it will be necessary to strategically reduce contact-rates. By reducing contact rates, the growth-rate of the outbreak can be reduced. Controlling contact rates is key to outbreak control, and such a strategy depends on population densities.

The basic reproduction number (R0) of SARS-COV-2 is often estimated around 2-4 (several times greater than for Influenza A).[1] The R0 have many determinants; including control-measures, such as social distancing and quarantine. Cruise ships are examples of dense-mixing of many persons in a confined space over a relatively long period.[4] The density of the group of people onboard the COVID-19-infected Diamond Princess, quarantined in Yokohama earlier this year, was estimated around four times higher than that in Wuhan, as was also the R0 before the onset of countermeasures.[4]

The relationship between the basic reproduction number, R_0, and the daily reproductive number, β, can be described by:

$$\beta = \tau c = \frac{R_0}{i},$$

where τ denotes transmissibility and c contact rate, and where the infectious period i equals one over the recovery rate γ. This relationship holds for well-mixed populations, as assumed by standard compartmental models like SIR or SEIR which apply the law of mass action, and are valid for small-to-medium spatial scales. The contact rate is directly related to the total number of contacts, $T(t)$, generated for any person over a time-period t, such that $T(t) = ctN$, for a situation with N persons. This means that the effect of the time-period of exposure and the crowd-size to $T(t)$ are equivalent.

As an example, consider a big music-event with a 50000-crowd, lasting 1/4 of a day, and compare this to a cruise ship with 2000 passengers for 6,25 days. Then, the total number of contacts in both cases are equal, as is given by:

$$T(0.25)_{music\ event} = c * 0{,}25 * 50000 = T(6.25)_{cruise\ ship} = c * 6{,}25 * 2000 = c * 12500.$$

For scenarios that are well described by models assuming well-mixed populations, the contact rate is proportional to population density. Thus, in the above example c differs between the music event and the cruise ship if the population per area is larger for the music event compared to the cruise ship. There are empirical observations suggesting population density in fact can have large impacts on the R0 through the contact rates. On the cruise ship the Diamond Princess, both the population density and R0 was estimated approximately four times greater than that in Wuhan [4]. For such proportionality, the contact rate can be written as a function of the density d, such that $c = md$, where m may be interpreted as the intensity of mixing. For any time-period t, the total number of contacts is then $T(t) = mdtN$, and in the case on Diamond Princess; $T(t) = 4md_W tN$ and $R_0 = 4md_W \tau i$, where d_W is the Wuhan population-density.

Keeping to more than one-meter distance between people coughing and sneezing, as recommended by the WHO[5], becomes more difficult with higher population-densities. Therefore, avoiding situations with higher population densities will be a necessary requirement to limit the spread of COVID-19.

References

1 RMH Anderson, H.; Klinkenberg, D.; Hollingsworth, T.D. How will country-based mitigation measures influence the course of the covid-19 epidemic? Lancet 2020; https://doi.org/10.1016/S0140-6736(20)30567-5(

2 J Hellewell, S Abbott, A Gimma, et al. Feasibility of controlling covid-19 outbreaks by isolation of cases and contacts. Lancet Glob Health 2020.

3 AN Tuite, V.; Rees, E.; Fisman, D. Estimation of covid-19 outbreak size in italy based on international case exportations. Pre-print medRxiv 2020; https://doi.org/10.1101/2020.03.02.20030049(

4 J Rocklov, H Sjodin, A Wilder-Smith. Covid-19 outbreak on the diamond princess cruise ship: Estimating the epidemic potential and effectiveness of public health countermeasures. J Travel Med 2020.

5 WHO: Coronavirus disease (COVID-19) advice for the public. https://www.Who.Int/emergencies/diseases/novel-coronavirus-2019/advice-for-public, access date: 11 March, 2020