Household Quarantine of Second Degree Contacts Is an Effective Non- Pharmaceutical Intervention to Prevent Tertiary Cases in the Current Pandemic

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Abstract

Background: Given the characteristics of SARS-CoV2 in regard to transmission before the onset of symptoms and varying manifestation indices according to age, isolation and quarantine have limited efficacy in the current pandemic. Household quarantine in second degree contacts (Hh-Q2°) outside the case household was so far only addressed by modellers. There is no publication based on field data in the literature.

Methods: In a retrospective cohort study on real field data from a county health department (CHD), all PCR-confirmed cases and related contact persons put into quarantine were analysed. Hh-Q2° was used in our CHD from the beginning of the pandemic.

Results: From 9 March to 8 December 2020, 353 PCR-confirmed cases were registered in the CHD Ploen, Northern Germany: 225 (63.7%) primary, 107 (30.3%) secondary and 21 (5.9%) tertiary cases. The 107 secondary cases resulted out of 470 (22.8%) close or 1°contacts and 21 tertiary cases out of 179 (11.7%) indirect or 2°contacts put into quarantine. The efficacy of Hh-Q2° was 51.5% (11.7%/22.8%) of the efficacy of quarantine in 1°contacts; 16.4% of all converted cases in quarantined persons were ascertained by Hh-Q2°. One in ten 1°contacts in households with tertiary cases remained asymptomatic.

Conclusion: The impact of Hh-Q2° in preventing further spread of SARS-CoV2 was considerable. With half the conversion rate in 2°contacts in comparison to 1°contacts, the efficacy of Hh-Q2° is substantial. Hh-Q2° should urgently be used routinely to control the spread of SARS-CoV2 more efficiently and national authorities should include it in their guidelines.

Background

Up to the just started launch of immunization against SARS-Coronavirus-2 (SARS-CoV2), control measures against the current pandemic relied on non-pharmaceutical interventions (NPI). Isolation of cases and quarantine of contact persons are measurements focusing on individuals or households. Given the parameters of SARS-CoV2 such as fraction of asymptomatic cases and transmission before the onset of symptoms, isolation and quarantine are of limited efficacy and can become quickly even more inefficient, if not carried out as fast and as comprehensive as possible [1, 2, 3, 4]. Therefore utmost effort is needed to increase the efficacy of isolation and quarantine. The earlier depends on the public health strategy and resources for testing available, the latter from the power of the local health departments. Household quarantine (Hh-Q) in general and Hh-Q of second degree contacts (Hh-Q2°) as a NPI tool in particular, is not consistently used in the current pandemic. So far the Robert Koch-Institute (RKI) as national centre for disease control in Germany recommends putting first degree contacts or close direct contacts (1°contacts) into quarantine. Exposure of the other household members by 1°contact, however, continues across the entire time of the quarantine of the 1°contacts at home, once the 1°contact starts shedding and transmitting, whether becoming symptomatic or not. Therefore the risk of not breaking the chain of transmission by only putting 1°contacts into quarantine instead of the entire

household is obvious. In our county health department (CHD), Hh-Q2° was used since the beginning of this pandemic.

The aim of this paper is to investigate and proof the impact and efficacy of Hh-Q2° to prevent tertiary cases and finally raise the efficacy of NPI.

Methods

In a retrospective cohort study of all confirmed cases in the responsibility of the County Health Department Ploen (CHD Ploen) and related quarantine orders triggered by the primary cases notified between 9 March and 8 December 2020, according to the German Infectious Diseases Control Act (IfSG) were eligible and analysed. In the CHD Ploen each PCR-confirmed case receives a consecutive case number. Cases #1 to #353 were investigated based on the referring in-house data base and the source documents at the time of contact tracing including information on household members. The duration of quarantine during this time period was 14 days according to the guideline of the Robert Koch-Institute (RKI) (www.rki.de). A quarantine of entire households can be ordered, if a case, finally confirmed by PCR, is diagnosed in a given household. These household members by definition would be 1°contacts, i.e. close direct contacts. By definition of the RKI, a close contact would be more than 15 minutes and below 1.5 meters distance without personnel protective equipment (PPE). Since the discussion around aerosols only came up later and was only integrated into the contact definition as off October 19, 2020, it is omitted here. The intensity of a 1°contact can be close (contact person type 1) or not as close (contact type 2) or under PPE (contact type 3). Often the primary case, most often also the index case, has 1°contacts outside of his own household (e.g. at the workplace). The household members besides the 1°contact(s) of a non-case household would be so called 2°contacts, who by definition only had indirect contact to the primary case via the household member, who was a 1°contact. In case the household members cannot separate themselves form the close contact within 72 hours (60–96 hours) of first exposure to the index case or separate at the time the close contact is tested negative, the entire household can incubate the virus, so that tertiary cases might occur beyond the secondary cases in 1°contacts. Transmission from the 1°contact can well start within the so-called prepatency period, the time window of viral shedding before onset of symptoms (i.e. before the end of the incubation period) [5]. Beyond this, the 1°contact can become symptomatic or not. Figure 1 explains the time windows and the fraction infected in the prepatency period especially adjusted to SARS-CoV2. The time windows are specific for a given virus. The index case in most constellations would also be the primary case of a chain of infection. A secondary case would for instance be a 1°contact person, who turns positive with or without symptoms. A tertiary case would be a contact person of the 1°contact, e.g. a household member of the 1°contact. Rarely, an index case could be a latter degree case such as a secondary or tertiary case and by this drawing the attention to the primary case by backward contact tracing. For pragmatic reasons, we call a 2°contact person turning positive or symptomatic a tertiary case, even when the 1°contact would remain asymptomatic. In analogy to Brockmann and Helbing [8], their wave model on international spread of pathogens via airports can be used to explain the contact chain and classify exposure of 1° and 2°.

To judge the impact of Hh-Q2° within the entire package of isolation and quarantine, the theoretical efficacy ε needed for control and θ, the fraction infected before a case can be identified (including asymptomatic cases), the central formula

$R_{eff} = (1- \theta)(1- \varepsilon)R_0 + \theta R_0$ (0)

is used. R_0 is the basic reproductive number and R_{eff} the effective reproductive number. According to Fraser et al. [1] the ε needed for control ($R_{eff} = 1$; $\theta = 0$) of a pathogen with a given R_0 is calculated by the formula

$\varepsilon > 1 - 1/R_0$ (3) (bracket refers to column in Table 2).

The ε_I (the ε of isolation) and ε_T (the ε of contact tracing and quarantine) together contribute to the effective ε (ε_{eff}). Since ε_I depends on the manifestation index and the amount of testing carried out, they are not under the control of the CHD. In contrary, ε_T in a given county is under the authority of a given CHD and therefore in focus here.

For $R_{eff} = 1$ and $\varepsilon = 1$, the central formula (0) describes θ with

$\theta R_0 < 1$ (4).

Since both, ε and θ, impact on ε_{eff} for SARS-CoV2 at the same time, the central formula has to be transformed to calculate ε_{eff}. Setting $R_{eff} = 1$, the control threshold, and replacing R_0 by $1 - 1/\varepsilon_{eff}$, results in

$\varepsilon_{eff} = 1-[(1- \theta)(1- \varepsilon) + \theta]$ (6 trough 10).

One scenario is calculated for a fraction of asymptomatic {F(asymt)} or missed cases of 20% (manifestation index = 80%; i.e. $\varepsilon_{max} = 80\%$) and another of 30% (manifestation index = 70%; i.e. $\varepsilon_{max} = 70\%$). The fraction of asymptomatic or missed cases increases with younger age [9]. The fraction asymptomatic and missed in the population obviously sets the limit of the ε maximal achievable (ε_{max}).

$\varepsilon_{max} = 100\% - F(asymt)$.

The “gap” for ε is calculated by $gap = \varepsilon - \varepsilon_{max}$ (5)

and

$gap = \varepsilon - \varepsilon_{eff}$ (6 through 10),

respectively.

The gap is a percentage or in case there is no gap, there is a puffer marked as a percentage “+”, i.e. a percentage which theoretically can be afforded not to be ascertained.

The fraction θ, if not intervened by quarantine, obviously is reducing the ε_{eff}. Therefore the aim of any control measures must be to reduce θ as much as possible by quarantine orders. Isolation fails in the asymptomatic or missed cases. In symptomatic and ascertained cases, quarantine of contacts is essential to reduce θ. Here prepatency period 2 is of practical importance (Fig. 1), i.e. until effective control measures are ordered [5]. Different θ and by quarantine reduced θ (>) are shown in columns (6) through (10). The gap here is calculated as gap = ε - ε_{eff}. ε taken form (3). The 95%-confidence intervals are used for continuous variables as well as proportions throughout. For the latter a normal distribution can be assumed given the size of the numbers.

Results

Within the study period, encompassing the entire first wave and a part of the second wave, a total of 353 (100%) PCR-confirmed cases were ascertained and all documents could be retrieved including information on the household members: 153 cases could be allotted to the first wave from 9 March to 31 August and 200 cases to the second wave as off 1 September to 8 December, the study end. The mean age in the first wave was 51.6 years [48.52; 54.72], in contrast to 42.1 years [39.19; 44.94] in the second wave.

A total of 225 primary cases were notified to our department based on the German Infectious Diseases Control Act (IfSG) via laboratories carrying out PCR-testing. A variety of test protocols were used in our region and ct-values are not forwarded by all laboratories to the CHDs. So far the cumulative incidence of SARS-CoV2/COVID-19 cases in Ploen County across the entire pandemic was the lowest in all of Germany (https://interaktiv.tagesspiegel.de/lab/karte-sars-cov-2-in-deutschland-landkreise). Figure 2 illustrates the geographical position of Ploen County and the 7-day cumulative incidence per 100.000 at the time of the beginning of the lockdown in the second wave in November 2020 [10].

The 225 primary cases came from 219 households and caused the quarantine of 649 individuals, 470 1°contacts and 179 2°contacts. Of the 470 1°contacts, 290 were in case households, 79 were in 63 households that consisted entirely of 1°contacts, and 101 came from 90 households that included 2°contacts. This study focuses on the 179 2°contacts in these 90 households (Table 1). The ratio between primary cases and quarantine orders was 1 to 2.1 (470 by 225) for 1°contacts and 1 to 2.9 (649 by 225) for all quarantine orders including 2°contacts.

The indication for Hh-Q2° was triggered by a delay of notification of the CHD by at least 72 hours (60–96 hours), if the household could not separate itself from the 1°contact or at least partially separate, if younger children or dependents have to be cared for, within this critical time window; or if the 1°contact could not be tested at the time separation within household was considered.

Of the 353 cases, there were 225 primary cases (63.7%), 107 cases (30.3%) among the 1°contacts (secondary cases), and 21 cases (5.9%) among 2°contacts (tertiary cases) (Fig. 3). The risk of infection among the 470 1°contacts was 22.8% [19.01; 26.59], and the risk of infection among the 179 2°contacts was 11.7% [6.99; 16.41]. This means that 1 in 4.4 quarantined 1°contacts and 1 in 8.5 2°contacts turned into a case. Of the 128 converted contacts, 16.4% occurred among 2°contacts. The efficacy of quarantine in 2°contacts was 51.5% of those in 1°contacts (11.7%/22.8% or 21/179 by 107/470).

The mean household size was considerably bigger in the households for which quarantine of 2°contacts was ordered (3.1 members in average). With 5.1 persons per household, the mean was the highest in the households with tertiary cases (Table 1). The 1°contact in one household, consisting of a total of 6 members, stayed asymptomatic, while a 2°contact became symptomatic and was PCR-confirmed. This shows that 1°contacts remaining asymptomatic are no guarantee that the virus does not spread further within the household. This is a proof of principle. Immediately after the closure of this study we had another constellation like this in the context of an important institution.

To judge the impact of 5.9% confirmed cases contributed by 2°contacts, a modelling given a fraction asymptomatic or oligosymptomatic (not ascertained) cases of 20 % and another of 30% is shown in Table 2. By using Hh-Q2° as NPI tool with at least 5.9% impact, a situation in a given column such as columns (6) through (9) can be shifted to the right by at least one, possibly even two columns, and by this into a more favourable situation (i.e. better control perspective). Given that 5.9% is the lower margin due to the issue of the manifestation index the effect is expected even to be bigger.

Discussion

Ploen County (population 128,686) is both, a spread out countryside (59% of the population) and a congested municipal residential area adjacent to the town of Kiel (245,000) with about the other 41% of the population. End of November 2020, Ploen county had a cumulative incidence in the second wave of around 130 per 100.000 and the city of Kiel of 330 per 100.000. For sure several reasons contribute to this difference, which cannot be further addressed in this place than just to mention that Hh-Q2° is not used in the CHD Kiel. The CHD Ploen is one of 15 health departments within the federal state of Schleswig-Holstein (2.8 million).

The first wave started in our region beginning of March, 2020. As of 9 March and enhanced at 23 March, lockdown measures were implemented and maintained until the first week of June, 2020. Already on 17 March the epidemic curve started to flatten. During the summer more and more restrictions were lifted and even big events were allowed. In August and September travel associated issues were on the forefront until the first week of October, when the second wave set in. As of 2 November, a lockdown light was implemented until 16 December, when another comprehensive lockdown was ordered.

Exposure and exposure measurement by contact tracing as a form of personal interview are key in field epidemiology [14]. How many persons to be put into quarantine depends obviously from several factors such as contact pattern, intensity of contact, the time axis, strategy towards direct and indirect contacts,

the societal structure, i.e. fraction of single household and household size, and particularly from the precision of the work of a CHD. The indication for Hh-Q2° was triggered by a delay of notification of the CHD by at least 72 hours (60–96 hours). This is twice the range of the minimum latency period of SARS-CoV2 (Fig. 1) [2, 7, 12]. Obviously this time window would need more modelling based on a bigger sample size, but according to our practical experience it seems to work. PCR testing at decision points in contact tracing and for separation within households is of great value.

The fraction of single households in our cohort was 29.8% (111 out of 372) and mirrors the societal structure with fewer families and children in general. With 2.1 (1°contacts only) and 2.9 (1° and 2°contacts) persons per primary case put into quarantine, this should be an acceptable burden for society and is much less than modelled by Aleta et al. [15] and Hinch et al. [16] or in the other CHDs in our region.

The efficacy of Hh-Q2° with 51.5% of the efficacy of quarantine in 1°contact was surprisingly high and obviously is influenced by the quality of the investigations by the CHD and the number of Hh-Q2° ordered (the denominator). Household size seems to be a major risk factor for conversion of contacts into cases or ascertainment of converted contacts as described also by a seroprevalence study in Sweden [17]. Adolescents and young adults were playing an increasing role in the second wave as 1°contact to households with further members according to the “heat chart” of age specific attack rates over time [10]. This age group to far extent still lives at their parents’ home and original family.

In this study 16.4% of all converted and symptomatic cases in quarantined persons were ascertained via Hh-Q2°. This means 1 in 6 cases were additionally prevented from further spreading the infection in the community. The all-over impact of Hh-Q2° detecting and containing 5.9% of all cases (21 out of 353) seems big enough to justify the effort of ordering quarantine for 2°contacts.

Hh-Q2° to prevent tertiary cases used early in an outbreak or a pandemic wave can make an impact and increase the efficiency of NPI. The early seeding of chains of infection can be prevented by Hh-Q and by this the virus running into a dead end. Hh-Q2° on a comprehensive scale is the preferable option in contrast to a lockdown of the general population. By Hh-Q2° a lockdown might be prevented or at least significantly delayed as also assumed by Aleta et al. [15]. To justify Hh-Q2° even more, investigations within contact tracing upstream have to be as accurate and as fast as possible to tailor the quarantine orders including Hh-Q2° only to the fraction of the contact pattern, in which exposure is most likely. Again this depends from the quality and efficiency of the work of the CHD. In spite of using Hh-Q2° as a tool in the CHD Ploen, the ratio of cases to quarantine orders was lower than in other CHDs in the region. The ultimate goal is to raise in spite of the counterproductive viral characteristics (Fig. 1). The manifestation index is founded in the virus-host interaction; the ascertainment of cases in the population in general depends from the amount of testing; but the management of quarantine and the use of Hh-Q2° are under the authority of the CHD.

In analogy to Brockmann and Helbing [8], the spread at the local level and even in the household setting can be looked upon in the same way (Fig. 3). The close contact would be the first wave, the hub, knocking on the door of the non-case household. If the household is not stratified in time, the incubation of the

entire household or setting continues in case the contact 1° starts to shed and renders into a case. The latter can only partially be identified in time given the key parameters of SARS-CoV2 such as θ including the fraction asymptomatic, but infectious subjects.

In general the household as an entity and endpoint of public health considerations is so far only partially recognized and accepted, since our health care thinking is to far extent focused on individual aspects. John Oxford [Vienna conference “Influenza Vaccines for the World”, 18 to 20 October 2006] pointed out for the first time and on many occasions thereafter that the 1918 pandemic (“Spanish Flu”) was primarily a tragedy of the families. Once the virus entered a family, the death toll was significant. The virus enters into families via one family member (a 1°contact) having had an efficacious contact outside. In analogy to the Japanese cluster approach for backward contact tracing [18], Hh-Q2° could be looked upon as the equivalent forward orientated control approach.

All measurements taken within the bundle of NPI also have to be seen under the aspect of compatibility with social aspects and by this raising acceptability and compliance. Ordering Hh-Q, at least due to the current regulation in Germany, is synergistic, since e.g. parents with children under quarantine do not have to bother about a sick leave or any other option to justify staying at home, since a quarantine order entitles them to social security and compensatory salary payment. The main argument, however, remains the public health intervention and blocking the chain of transmission. Anyway the conversion of the 1°contact into a case with shedding at least two days before symptom onset or as an asymptomatic spreader is the cornerstone of the argument for Hh-Q2°. According to our observations about one in 10 tertiary cases occurs without symptoms in the close contact of that household.

The inability and time delay of detection of this conversion with onset of viral shedding caused by the fraction θ including the fraction of asymptomatic, are facts and surveillance of 1°contact by health departments is necessarily inefficient due to the time and shedding characteristics of SARS-CoV2. The most recent data by Zhang et al. makes this effort appear even more inefficient since they pointed out that even with tight testing of household members in quarantine many are missed as their serological data revealed [19]. Beyond this, the numbers of quarantine are quickly rising in a pandemic wave and the manpower bound by active surveillance is accumulating accordingly. This manpower could better be used otherwise, for instance in ambulatory testing of clusters.

Since incubation of the household continues over the entire period of a 1°contact, if it starts to shed virus, the up to now 14 days of quarantine are supportive for the efficacy of Hh-Q2°. A shortening of the quarantine duration from 14 to 10 days could have a detrimental impact, since the 14 days so far, guaranteed to most extend that 2°contacts would still be in quarantine at the time of being transmissible, whether symptomatic or not, after being infected by a 1°contact.

Finally all this has to be driven by the motivation to contain or flatten the pandemic wave to protect the vulnerable but still limiting the burden for the general society as much as possible. The tool of Hh-Q2° is easy to order and logical at the same time. It is stunning that it was widely overlooked and not identified at least by authorities as a straight forward measurement within the tool box of NPI so far. So far it was

only addressed by modellers [15, 16]. Across the entire sessions concerning SARS-CoV2 and COVID-19 during the ESCAIDE conference 26 and 27 November 2020, organised by the ECDC, it was only mentioned on one slide within the key note lecture by George Gao, head of the Centre for Disease Control China, in regard to lessons learned in China [20]. As demonstrated within the study presented here, Hh-Q2° is also feasible in Western countries. We advocate giving Hh-Q2° a higher priority within the tool box of NPI, at least for the control of SARS-CoV2, as did already Aleta et al. [15]. Whether it is more widely used than made public, remains an open issue. If explained to persons to be put under Hh-Q, it is widely accepted since plausible. Hh-Q2° is to a far extent not yet addressed in national guidelines, since it has to come from the field and is easily overlooked by national authorities. The RKI should urgently integrate the approach demonstrated here into their national guidelines. The tool of Hh-Q2° is logic and straight forward at the same time.

Limitations

The study design was retrospective, but the documentation of the source population was sufficiently detailed. The power of the study was limited given the size of the local population and the low incidence. Household members were either tested negative or not tested supposedly due to no symptoms. This mirrors a real life situation. One could speculate that Hh-Q2° was even much more efficacious since it also prevented asymptomatic persons within the 2°contacts from transmitting beyond their own household. This would mean that the impact of household quarantine was underestimated in this study by at least 20%. The eligibility for Hh-Q2° might have been selective, but is a standard option in our department. Finally the base for the case definition could be limited by false positive PCR tests. The strength of the study presented here, however, is that these are real life data and practical issues around them are addressed instead of modelling with varying assumptions.

Conclusions

Given the impact of Hh-Q2° and the output of tertiary cases from the number of persons put into quarantine, Hh-Q2° is an effective tool to increase the efficacy of quarantine measures. It should be used more readily after detailed investigations of the contact pattern and timelines to overtake the virus in its spread. Hh-Q2° can even be critical for prevention or containment of local outbreaks of SARS-CoV2. We think we have identified a common gap within the portfolio of NPI measurements, which easily can be implemented and carried out in a differentiated or crude form. It is unlikely that the cumulative incidence in Ploen County is the lowest in Germany just by chance.

The pandemic revealed weaknesses in the local health departments, which finally have to be closed as fast as possible. In the meantime, the available manpower has to be used as efficiently as possible. Inefficient approaches have to be omitted immediately. Hh-Q2° is as simple and straight forward as we wished other interventions to be. The burden for a few should be acceptable in favour of avoiding or at least postponing measurements for the entire society such as lockdowns.

Abbreviations

CHD: county health department; Hh-Q2°: household quarantine in 2°contacts in household different form the case household; NPI: non-pharmaceutical interventions; 1°contact: a close (direct) contact; 2°contact: a (indirect) contact to a close contact.

Declarations

Ethics approval and consent to participate:

Given that this study is a retrospective chart review of routine work and considered quality assurance, the collection of consent to participate and submission of the study to an ethics committee was deemed unnecessary, according to the current legislation of the German Infectious Diseases Control Act (Infektionsschutzgesetz). All methods were carried out in accordance with relevant guidelines and regulations. No administrative permissions and/or licenses were required to access the clinical/personal patient data since all data are under full authority by our department, the County Health Department Ploen (i.e. the Public Health Institute Ploen).

Consent for publication:

not applicable

Availability of data and material:

The datasets generated and analysed during the current study are not publicly available but are available from the corresponding author on reasonable request after de-identification.

Competing interests:

The authors declare that they have no competing interests.

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none

Authors' contributions:

AKF and MS extracted additional data from the source files, managed the data base and verified the data. JW developed the strategy, the concept and the study design, evaluated, analysed and interpreted the data and wrote the manuscript.

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Tables

Table 1
Overview of 353 confirmed cases and type of quarantine ordered from 9 March to 8 December 2020 in the County Health Department Ploen

Cases and contacts by definition	households exposed	primary cases	C1° exposed	secondary cases (C1°positive)	C2° exposed	tertiary cases (C2° positive)
Primary cases	**219 total**	**225**	**290**	**-**	**n/a**	**n/a**
1°contact (Hh the same as primary case) Hh quarantine based on direct exposure (mean Hh size = (225 + 290)/219 = 2.35)	56 single	56	-	-	n/a	n/a
	112 multiple w/o sec. cases	118	188	-	n/a	n/a
	51 multiple with sec. cases	51	102	61	n/a	n/a
1°contact (different Hh as primary case) without 2°contacts Hh quarantine based on direct exposure (mean Hh size = (79/63 = 1.25)	**63 total**	**n/a**	**79**		**n/a**	**n/a**
	40 single – no case	n/a	40	-	n/a	n/a
	15 single – as case	n/a	15	15	n/a	n/a
	8 multiple – all exposed	n/a	24	10	n/a	n/a
1°contact (different Hh as primary case) with 2°contacts; for the latter Hh quarantine based on indirect exposure (mean Hh size = (101 + 179)/90 = 3.11) (mean Hh size = (8 + 32 + 1 + 5)/9 = 5.11)*	**90 total**	**n/a**	**101**		**179**	
	68 without contact 1° pos.	n/a	78	-	111	-
	13 with contact 1° pos.only	n/a	14	13	31	-
	8 with contact 2° pos.	n/a	8	8	32	20
	1 with contact 2° pos.	n/a	1	-**	5	1

Hh = household (single vs. multiple, i.e. more than one Hh member) C1° directly exposed contact C2° indirectly exposed contact

* Household size for the households with converted 2°contacts

**one 1°contact was asymptomatic, not tested but 2°contact in household turned symptomatic and confirmed PCR-positive

Cases and contacts by definition	households exposed	primary cases	C1° exposed	secondary cases (C1°positive)	C2° exposed	tertiary cases (C2° positive)
total	372	**225**	470	**107**	179	**21**
353 cases total (100%)		(63.7%)		(30.3%)		(5.9%)
Hh = household (single vs. multiple, i.e. more than one Hh member) C1° directly exposed contact C2° indirectly exposed contact						
* Household size for the households with converted 2°contacts						
**one 1°contact was asymptomatic, not tested but 2°contact in household turned symptomatic and confirmed PCR-positive						

Table 2. Efficacy (ε) of isolation and quarantine given a fraction (F) asymptomatic (missed cases) and a fraction θ of transmissions before symptom onset

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Fraction (asymptomatic or missed cases) = 20%					F(asympt)20%	F(asympt)20%	F(asympt)20%	F(asympt)20%	F(asympt)20%
				ε_{max} = 80%	θ=30%	θ = 20%	θ = 20% >10%	θ = 20% > 5%	θ = 20% > 0%
reference	R_0	ε	θ	gap	ε_{eff}=56% gap	ε_{eff} = 64% gap	ε_{eff} = 72% gap	ε_{eff} = 76% gap	ε_{eff} = 80% gap
	(abs.)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
	6	83	17	3	27	19	11	7	3
Sanche [11]	5.7	82	18	2	26	18	10	6	2
	5	80	20	0	24	16	8	4	0
	4	75	25	5+	19	11	3	1+	5+
PAHO [12]	3.7	73	27	7+	17	9	1	3+	7+
	3	67	33	13+	11	3	5+	9+	13+
Ferguson [13]	2.4	59	41	21+	3	5+	11+	17+	21+
	2	50	50	30+	6+	14+	22+	26+	30+
Fraction (asymptomatic or missed cases) = 30%					F(asympt)30%	F(asympt)30%	F(asympt)30%	F(asympt)30%	F(asympt)30%
				ε_{max} = 70%	θ = 30%	θ = 20%	θ = 20% > 10%	θ = 20% > 5%	θ = 20% > 0%
reference	R_0	ε	θ	gap	ε_{eff} = 51% gap	ε_{eff} = 56% gap	ε_{eff} = 63% gap	ε_{eff} = 67% gap	ε_{eff} = 70% gap
	(abs.)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
	6	83	17	13	32	27	20	16	13
Sanche [11]	5.7	82	18	12	31	26	19	15	12
	5	80	20	10	29	24	17	13	10
	4	75	25	5	24	19	12	8	5
PAHO [12]	3.7	73	27	3	22	17	10	6	3
	3	67	33	3+	16	11	4	0	3+
Ferguson [13]	2.4	59	41	11+	8	3	4+	8+	11+
	2	50	50	20+	1+	6+	13+	17+	20+

R_0 = basic reproductive number for SARS-CoV2

ε = efficacy of isolation and quarantine ($\varepsilon_I + \varepsilon_T$); (3) $\varepsilon > 1\text{-}1/R_0$ according to Fraser et al. [1]

θ = fraction of transmission before symptom onset; (4) θ R_0 < 1 according to Fraser et al. [1]

(5) gap = ε - ε_{max} , the difference between ε needed according to ε > 1-1/R_0 (column 3) and ε_{max}, given a certain fraction of asymptomatic or missed cases; in case the gap is %+, this means a puffer of allowed insufficiency before ε > 1-1/R_0 is reached

(6) to (10) ε_{eff} resulting out of F(asymptomatic) in the general population + θ the fraction infected before the onset of symptoms; gap = ε - ε_{eff}

Percentages are rounded up to the next whole number

Figures

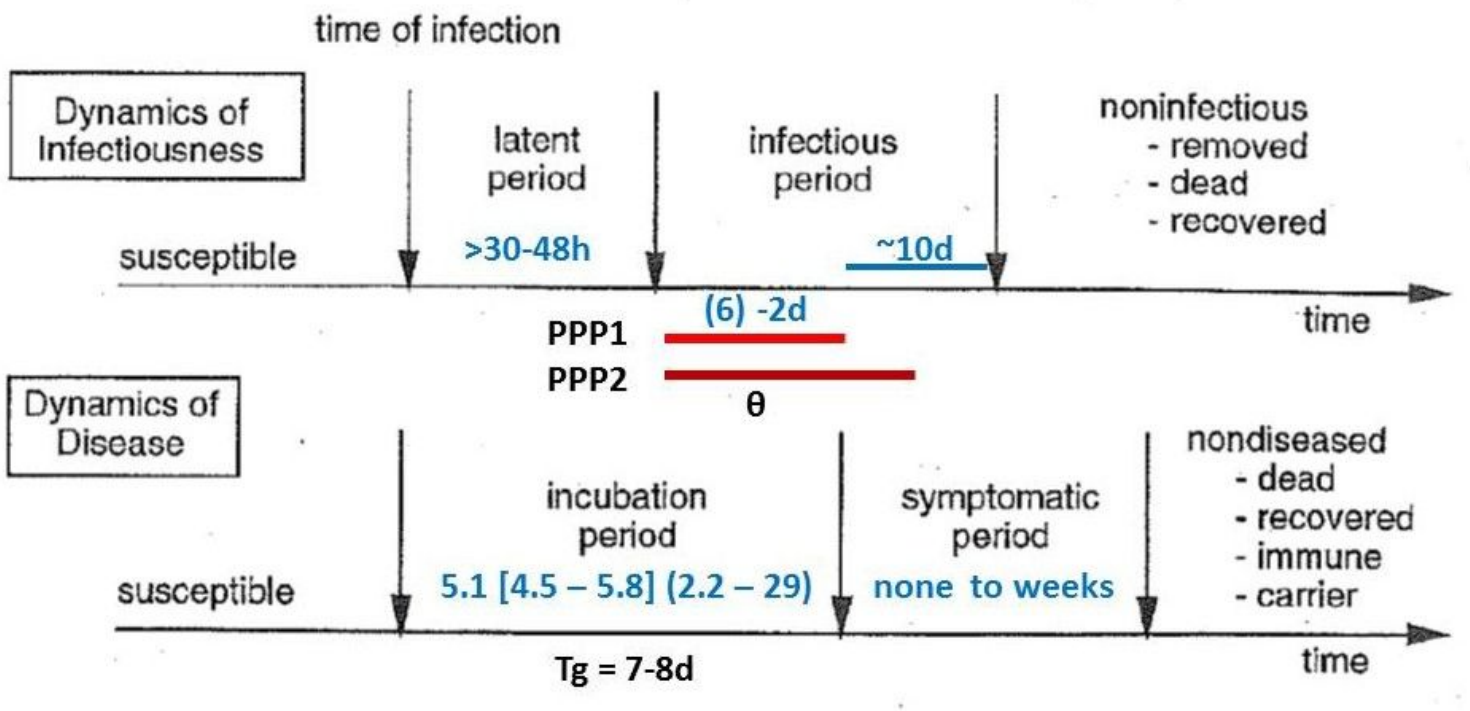

Figure 1

Critical timelines of SARS CoV2 from the perspective of the virus and the host, respectively (in analogy to Halloran [6]) The parameters for SARS-CoV2 are inserted into the didactic figure by Halloran within the referring chapter in the classical textbook by Rothman and Greenland [6]. Dynamics of infection refers to the perspective from the virus. Dynamics of disease refers to the host, the human. Tg generation time; PPP1 prepatency period 1: time from start of viral shedding to start of symptoms [5]; PPP2 prepatency period 2: from start of viral shedding to isolation [5]; θ: fraction infected before onset of symptoms or isolation, respectively [1]; incubation period according to Lauer et al. [7]

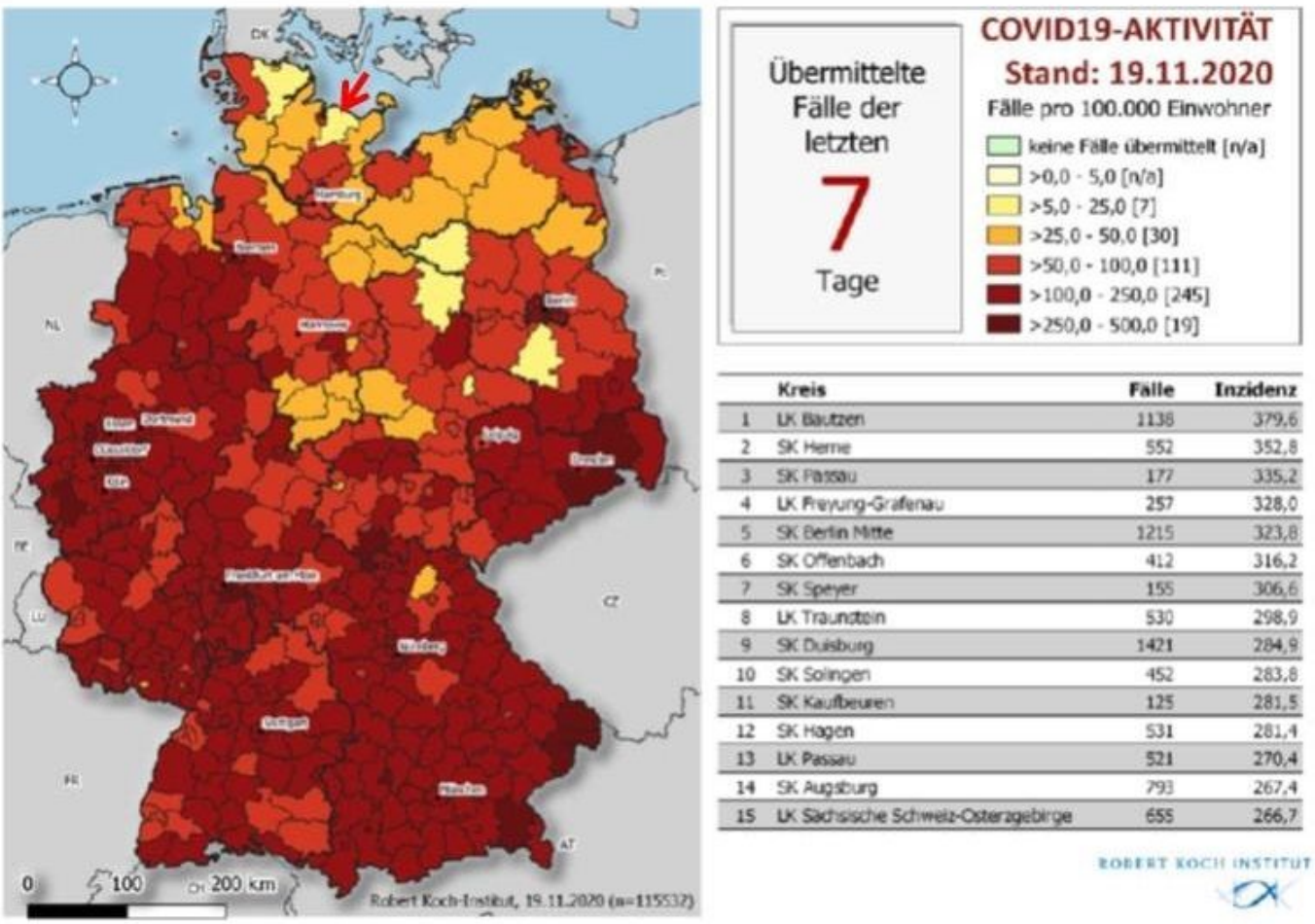

Figure 2

Catchment area and 7-day cumulative incidence on 19 November 2020 [10], arrow marks Ploen county east of the town of Kiel on the Baltic seashore. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

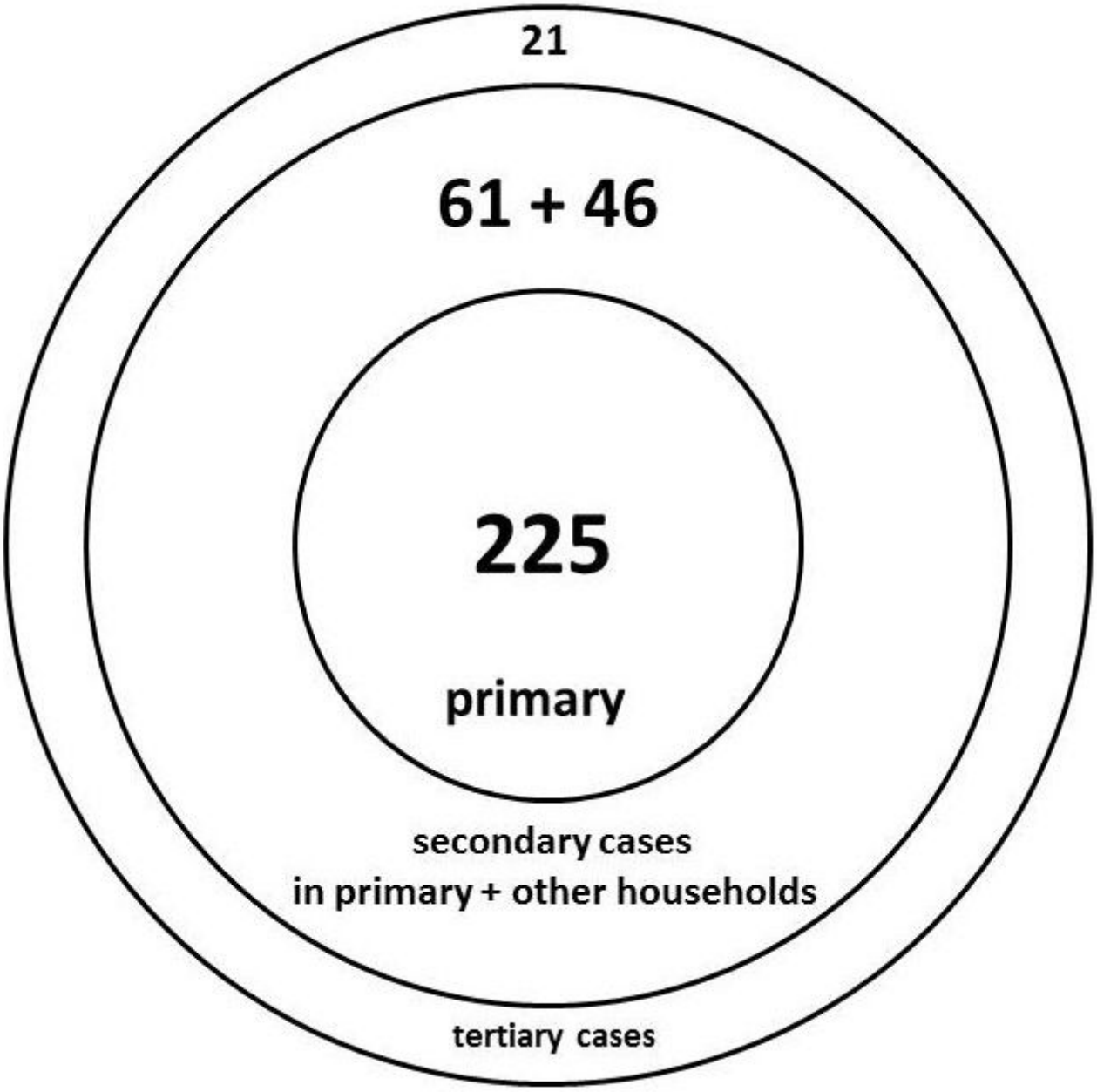

Figure 3

Waves of transmission of 353 confirmed cases form 9 March to 8 December 2020, County Health Department Ploen