Impact of vaccination on household transmission of SARS-COV-2 in England

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Introduction

Vaccination against SARS-CoV-2 with either ChAdOx1 nCoV-19, produced by Astra-Zeneca, or BNT162b2, produced by Pfizer, has been shown to produce a robust antibody response (1,2), and is effective in both preventing cases and reducing the severity of COVID-19 in vaccinated individuals(3,4). While fewer cases will reduce disease burden, it is not yet clear whether these vaccinations will also reduce transmission in the minority who have been vaccinated but develop post-vaccination infection.

Vaccination commenced in England in December 2020 targeting priority groups 1 and 2 (Box 1) (those at highest risk of mortality from COVID-19 and frontline health and social care workers) with BNT162b2. Rollout expanded from 4 January 2021 with ChAdOx1 nCoV-19, targeting the top 4 priority groups (Box 1). Fifteen million vaccinations were given to

individuals in these groups by 15 February 2021, and all individuals in the top 9 groups had been offered their first vaccination by 13 April 2021(5).

During the second pandemic wave, cases of and deaths from COVID-19 in England peaked in late December 2020 and early January 2021 respectively after the end of November's lockdown measures; the increase in cases in December 2020 also coincided with the emergence of new variants of SARS-CoV-2 such as VOC202012/01(8). The combined effects of a new national lockdown in late December 2020 with school closures and the roll out of the vaccination programme saw cases of and deaths from COVID-19 fall through out January and February 2021, reaching between 3-4000 cases per day by end March 2021 (9).

Box 1. Priority groups for vaccination in England(6)

Priority	**Risk group**
1	Residents in a care home for older adults and staff working in care homes for older adults
2	All those 80 years of age and over and frontline health and social care workers
3	All those 75 years of age and over
4	All those 70 years of age and over and clinically extremely vulnerable(7) individuals (not including pregnant women and those under 16 years of age)
5	All those 65 years of age and over
6	Adults aged 16 to 65 years in an at-risk group and unpaid carers
7	All those 60 years of age and over
8	All those 55 years of age and over
9	All those 50 years of age and over
10	Rest of the population (to be determined)

Household contacts of confirmed cases are at high risk of infection and this setting is an important route of transmission overall(10); studies internationally have shown secondary attack rates (SAR) within households vary from 3.9%(11) to 37% (12), depending on the setting, lockdown measure, and methods of ascertaining cases (active versus passive), with an overall secondary attack rate in households estimated at 16.6% in a recent systematic review and meta-analysis(13). Published analysis of passive surveillance data from England shows an average SAR of 5.9% between June and September 2020(14), but this represents the nadir of the epidemic in England and in our routine analyses we have seen the SAR rise above 10% in December 2020.

As a high risk setting for transmission, households can provide early evidence for impacts of interventions, such as vaccines, in preventing the onward transmission from an index case to household contacts. Although based on a specific setting, this may have implications for transmissibility in other settings, where transmission risks may be similar.

The risk of transmission of SARS-CoV-2 to other people after vaccination can only be studied in the small proportion of individuals who develop infection despite having been vaccinated. The purpose of this study was to determine whether individuals who have received one dose of vaccine but still become infected with SARS-COV-2 up to 60 days after the first dose, are less likely than unvaccinated cases to transmit to their unvaccinated household contacts.

Methods

Dataset creation

The creation of the routine HOSTED dataset has been described in detail elsewhere(14). In brief, laboratory confirmed cases of COVID-19 in England which are reported to national laboratory surveillance systems(15) are linked to individuals who share the same address, using National Health Service (NHS) number and the Unique Property Reference Number

(UPRN). Known institutional settings (using UPRN information) such as care homes, prisons, and households with more than 10 residents are excluded.

For this analysis, the HOSTED dataset was linked to data from the National Immunisation Management System (NIMS)(16) to obtain information such as the dates and types of COVID-19 vaccinations for all individuals vaccinated in England.

Dataset description

HOSTED includes individual-level socio-demographic data for cases and household contacts, including age, sex, and Index of Multiple Deprivation (IMD); information on property type, confirmed cases using PCR-based SARS-CoV-2 through national reporting systems, and linked information on hospitalisation and mortality. The vaccination data include date and type (ChAdOx1 nCoV-19 or BNT162b2) of first and second doses for all vaccinated individuals in the HOSTED dataset.

Data preparation

We defined *Index Cases* as the earliest case of laboratory-confirmed COVID-19, by diagnosis date, for a household. *Household Contacts* were defined as all individuals with the same address as the index cases of COVID-19; and *Secondary Cases* as a known household contact of an index case with a positive SARS-CoV-2 test that has a specimen date between 2 and 14 days after the specimen date of the index case.

The analysis cohort included households with an index case occurring between 4 January 2021 to 28 February 2021, with 14 days observable follow up for all contacts. Households in which *any* individual was vaccinated prior to the 4 January were excluded, so that our analysis would be as broadly generalizable as possible to the overall vaccination campaign. Households in which the index case was vaccinated 1-14 days after testing positive for COVID-19 were also excluded, as were all contacts who had been vaccinated prior to the index case testing positive. We excluded index cases tested under ‘pillar 1’ of the national testing strategy, which is a proxy for a case being either hospitalised or a health worker. This

was because the household contacts of hospitalised cases are likely to have differential exposure profiles compared to contacts of non-hospitalised cases. Finally, we restricted analyses to households with a single index case age 16+, and no co-primary cases (any other cases on the same or next day as the index case).

Statistical analysis

We defined *vaccinated* index cases as having been vaccinated 21 days or more prior to testing positive for COVID-19 based on evidence of the time needed for the vaccine to provide a sufficient level of immunity(17). *Non-vaccinated* index cases were defined as not having received a vaccine prior to testing positive. Households where the index case received the vaccine less than 21 days before testing positive were excluded from this analysis.

We compared household contacts of index cases receiving either the ChAdOx1 nCoV-19 or BNT162b2 vaccines, with contacts of unvaccinated index cases, and the proportion of contacts who tested positive within 2-14 days of the index case (*secondary cases*) in each group: unvaccinated (base group), BNT162b2, and ChAdOx1 nCoV-19.

The odds of being a secondary case was modelled using logistic regression, adjusted for the following covariates: age of index case and contact (ages grouped as 0-15, 16-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80+), sex of index case and contact, government office region (9 groups), calendar week of index case, index of multiple deprivation quintile (IMD) and household type. Household types were defined as in previous work(14) and further subdivided by size to give the following groups: pairs/couples of adults both age under 65; pairs/couples of adults with one or both 65+; households with children (<16) of size 2-4, 5-7 and 8-10; multi-generational households (at least one adult age 65+ and age gaps of at least 16 years between this adult and 2 younger household members) of size 3-4, 5-7 and 8-10; and 3+ adult-only households of size 3-4, 5-7 and 8-10.

We used robust standard errors in the final model to allow for dependence between individuals in the same household. Results are presented in terms of odds ratios (ORs) and 95% confidence intervals (CI).

We also conducted a matched case-control study, matching secondary cases and non-cases on the basis of age group and sex of index case and contact, region, week, IMD quintile, and household type. This analysis was intended to ensure balanced covariates in cases and non-cases, as there may be complex inter-relationships between covariates. Odds ratios of infection in the household contacts were estimated using conditional logistic regression.

In addition to a binary exposure (vaccinated 21+ days before becoming an index case vs. unvaccinated) we considered households in which the index case was vaccinated any time up to the date of testing positive, in whom there may be a partial effect on transmission. Timing of vaccination was grouped in 2-to-3 day intervals in the 0-24 days prior to testing positive, then at 4, 5, or more than 6 weeks prior to testing positive. The odds of being a secondary case according to vaccination timing (vs. unvaccinated index case) was modelled using the same logistic regression model described above and we examined the timing according to age of index case and contact, and calendar time (January and February).

Finally, we compared households in which the index case was vaccinated 21-35 days before testing positive with households in which the index case was vaccinated 1-10 days before testing positive. Three sets of analyses were conducted; a multivariable logistic regression model including the covariates specified above; a matched case-control study; and a stratified cohort study. Matching/stratification was first conducted on age group of index case and contact, plus the week of index case vaccination. The latter was to ensure the groups were comparable in terms of index case vaccination timing, and differed only in the timing of subsequently testing positive. We then added further variables to the stratification/matching: sex of index case and contact, region, IMD quintile, and household type.

Results

Description of the data set

Data were extracted on 23 March 2021 and included individuals with at least 14 days of observable follow-up from the date of specimen collection from the index case (i.e. index cases between 4 January 2021 to 28 February 2021, secondary cases up to 14 March 2021). There were 552,984 residential households of 2 to 10 people where there was at least one case. Table 1 shows the exclusions applied to arrive at the final analysis cohort.

Table 1. Numbers of households, contacts of index cases, and secondary cases in the data, numbers excluded according to different criteria, total exclusions, and final analysis cohort.

	Households	**Contacts**	**Secondary cases**
Starting cohort	552,984	1,449,427	147,109
Exclusions (overlapping criteria)			
Multiple index/co-primary cases	83,960	146,193	17,944
Index case age under 16	23,560	69,213	8,120
Index case tested in pillar 1	65,270	153,821	12,448
Index case vaccinated prior to 4 January 2020	21,475	54,904	4,991
Index case vaccinated 2-14 days after testing positive	3,849	8,283	516
Contacts vaccinated prior to index case date	59,161	67,622	8,152
Total exclusions (any criteria)	211,276	430,585	44,447

Households where no remaining contacts after exclusions	8,435	0	0
Final cohort	365,447	1,018,842	102,662

The exclusion criteria did not overlap substantially, although contacts in households where the index case was vaccinated prior to 4 January 2021 were more likely to have been vaccinated (28.6% vs. 3.7%). The final cohort consisted of 365,447 households with a single index case and 1,018,842 contacts. There were 4,107 households where the index case was vaccinated 21 days or more before testing positive (1.12%), and 20,110 where the index case was vaccinated less than 21 days before testing positive (5.51%). Table 2 shows characteristics of contacts according to vaccination status of the index case.

Table 2. Characteristics of household contacts according to vaccination status of index case.

	Unvaccinated index case		**Index case vaccinated 21+ days before +ive**		**Index case vaccinated <21 days before +ive**	
	N	**col %**	**N**	**col %**	**N**	**col %**
Age of index case						
16-29	302,600	31.5%	1,750	18.7%	9,436	19.7%
30-39	259,731	27.0%	2,269	24.2%	11,178	23.3%
40-49	196,898	20.5%	2,215	23.7%	11,277	23.5%
50-59	138,531	14.4%	2,074	22.2%	9,981	20.8%
60-69	50,538	5.3%	743	7.9%	4,157	8.7%
70-79	10,031	1.0%	181	1.9%	1,289	2.7%
80+	2,436	0.3%	131	1.4%	632	1.3%
Age of contact						

	Unvaccinated index case		Index case vaccinated 21+ days before +ive		Index case vaccinated <21 days before +ive	
	N	col %	N	col %	N	col %
0-15	263,190	27.4%	2,969	31.7%	13,429	28.0%
16-29	221,231	23.0%	2,321	24.8%	11,630	24.3%
30-39	141,858	14.8%	1,216	13.0%	6,276	13.1%
40-49	117,352	12.2%	965	10.3%	5,258	11.0%
50-59	126,144	13.1%	1,210	12.9%	6,388	13.3%
60-69	64,166	6.7%	574	6.1%	3,679	7.7%
70-79	20,388	2.1%	77	0.8%	1,020	2.1%
80+	6,436	0.7%	31	0.3%	270	0.6%
Sex						
Male	503,099	52.4%	5,776	61.7%	28,460	59.4%
Female	457,666	47.6%	3,587	38.3%	19,490	40.6%
Index case date						
04 Jan - 10 Jan	293,672	30.6%	0	0.0%	1,618	3.4%
11 Jan - 17 Jan	219,283	22.8%	0	0.0%	8,242	17.2%
18 Jan - 24 Jan	151,170	15.7%	0	0.0%	12,180	25.4%
25 Jan - 31 Jan	101,926	10.6%	334	3.6%	10,182	21.2%
01 Feb - 07 Feb	73,531	7.7%	1,302	13.9%	6,908	14.4%
08 Feb - 14 Feb	49,759	5.2%	2,117	22.6%	3,887	8.1%
15 Feb - 21 Feb	42,509	4.4%	3,004	32.1%	2,786	5.8%
22 Feb - 28 Feb	28,915	3.0%	2,606	27.8%	2,147	4.5%
IMD quintile						
1	265,475	27.6%	2,486	26.6%	11,070	23.1%
2	239,131	24.9%	2,065	22.1%	10,850	22.6%
3	184,066	19.2%	1,930	20.6%	10,099	21.1%
4	149,319	15.5%	1,556	16.6%	8,720	18.2%
5	122,774	12.8%	1,326	14.2%	7,211	15.0%

	Unvaccinated index case		Index case vaccinated 21+ days before +ive		Index case vaccinated <21 days before +ive	
	N	col %	N	col %	N	col %
Region						
East Midlands	79,301	8.3%	1,310	14.0%	5,180	10.8%
East of England	102,804	10.7%	931	9.9%	5,973	12.5%
London	229,362	23.9%	571	6.1%	5,442	11.3%
North East	32,640	3.4%	390	4.2%	1,795	3.7%
North West	132,466	13.8%	1,730	18.5%	6,991	14.6%
South East	139,455	14.5%	1,156	12.3%	8,440	17.6%
South West	58,015	6.0%	811	8.7%	4,433	9.2%
West Midlands	122,359	12.7%	1,594	17.0%	6,453	13.5%
Yorkshire and The Humber	64,363	6.7%	870	9.3%	3,243	6.8%
Household type						
Adult pair/couple	51,802	5.4%	733	7.8%	3,547	7.4%
Older pair/couple	14,006	1.5%	143	1.5%	1,260	2.6%
HH with children, 2-4	200,338	20.9%	2,469	26.4%	11,322	23.6%
HH with children, 5-7	212,808	22.1%	1,931	20.6%	8,952	18.7%
HH with children, 8-10	57,688	6.0%	314	3.4%	1,449	3.0%
Multi-gen HH, 3-4	9,876	1.0%	142	1.5%	701	1.5%
Multi-gen HH, 5-7	53,814	5.6%	496	5.3%	2,728	5.7%
Multi-gen HH, 8-10	31,917	3.3%	139	1.5%	1,137	2.4%
Adult only, 3-4	208,556	21.7%	2,264	24.2%	12,093	25.2%
Adult only, 5-7	98,479	10.3%	632	6.7%	4,158	8.7%
Adult only, 8-10	21,481	2.2%	100	1.1%	603	1.3%

In all households, the majority of index cases and contacts were age <60, with a high proportion of individuals aged <40 in unvaccinated households. Over half of contacts were

also aged <40 for all household groups. Male contacts were more common in households in which the index case had been vaccinated. As households where the index case had been vaccinated for 21+ days before being infected required a 3-week window, there are no households in this group with an index case between 4 and 24 January; otherwise, index cases approximately follow the overall case rate, as described above. Distributions of IMD, region and household size were generally similar between the vaccinated and unvaccinated groups.

Vaccine effect on transmission

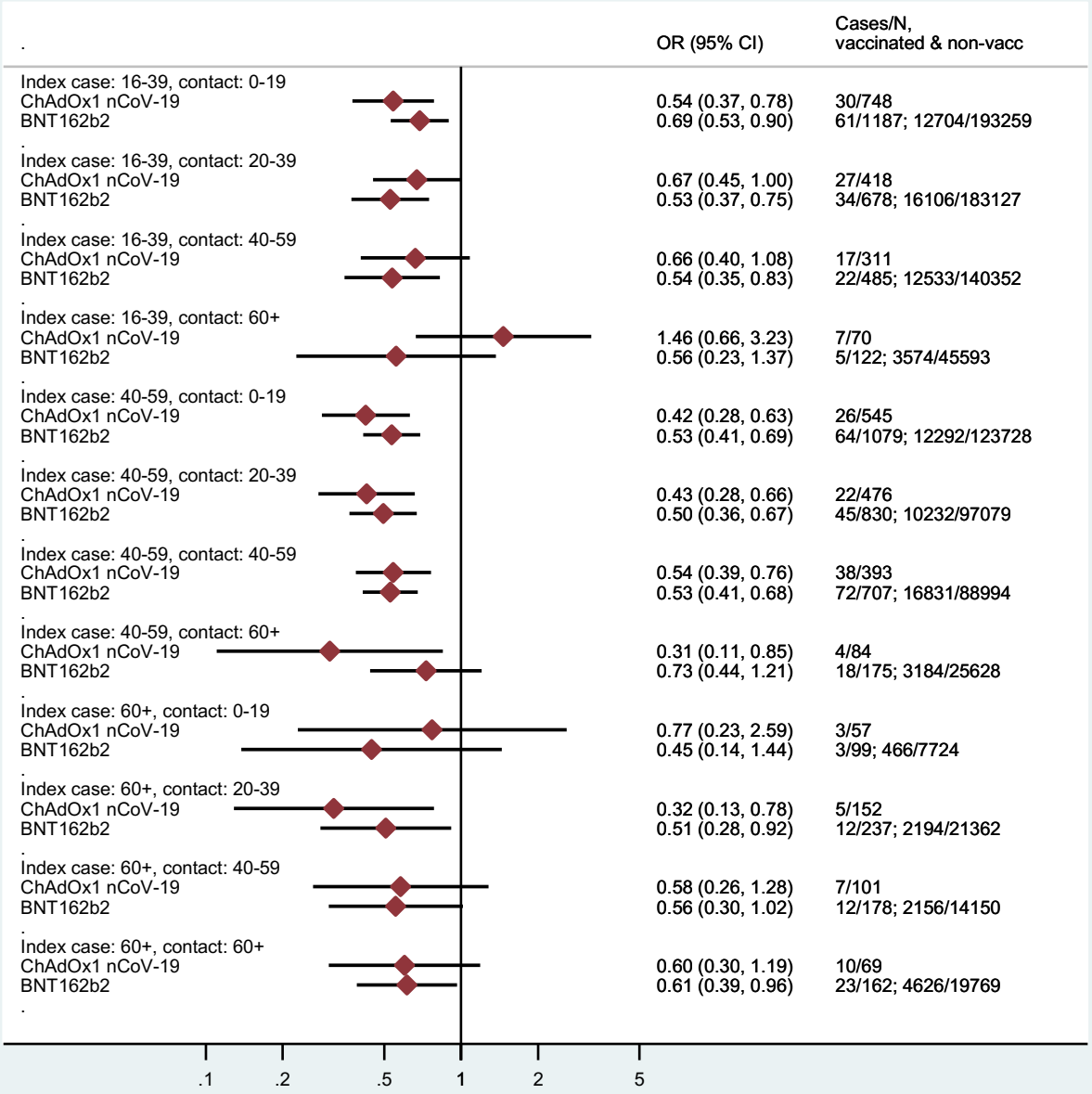
In households where the index case was not vaccinated before testing positive, there were 96,898 secondary cases out of 960,765 household contacts (10.1%). There were 196 secondary cases in 3,424 contacts (5.72%) where the index case received the ChAdOx1 nCoV-19 vaccine 21 days or more before testing positive, and 371 secondary cases in 5,939 contacts (6.25%) where the index case received the BNT162b2 vaccine 21 days or more before testing positive.

The unadjusted odds ratio for being a secondary case if the index case was vaccinated with ChAdOx1 nCoV-19 21 days or more before testing positive (vs. index case not vaccinated) was 0.55 (95% CI 0.46, 0.67), and for BNT162b2, 0.57 (95% CI 0.49, 0.65). Results from the multivariable model were similar, with an adjusted OR of 0.53 (95% CI 0.43, 0.63) for ChAdOx1 nCoV-19 and 0.51 (95% CI 0.44, 0.59) for BNT162b2. Full results from the multivariable logistic regression model are given in Supplementary Material S1. There was little evidence for effect modification by age of index case (likelihood ratio p-value=0.085) or age of contact (p=0.177). Figure 1 shows estimates for each vaccine according to the age of the index case and age of contact.

In the matched case-control study, 1,513 contacts of index cases vaccinated with ChAdOx1 nCoV-19 (64%) were matched to contacts with unvaccinated index cases, with an estimated OR of infection of 0.62 (95% CI 0.48, 0.79). There were 2,694 contacts of index cases

vaccinated with BNT162b2 (67%) matched to contacts with unvaccinated index cases, with an estimated OR of 0.51 (95% CI 0.42, 0.62).

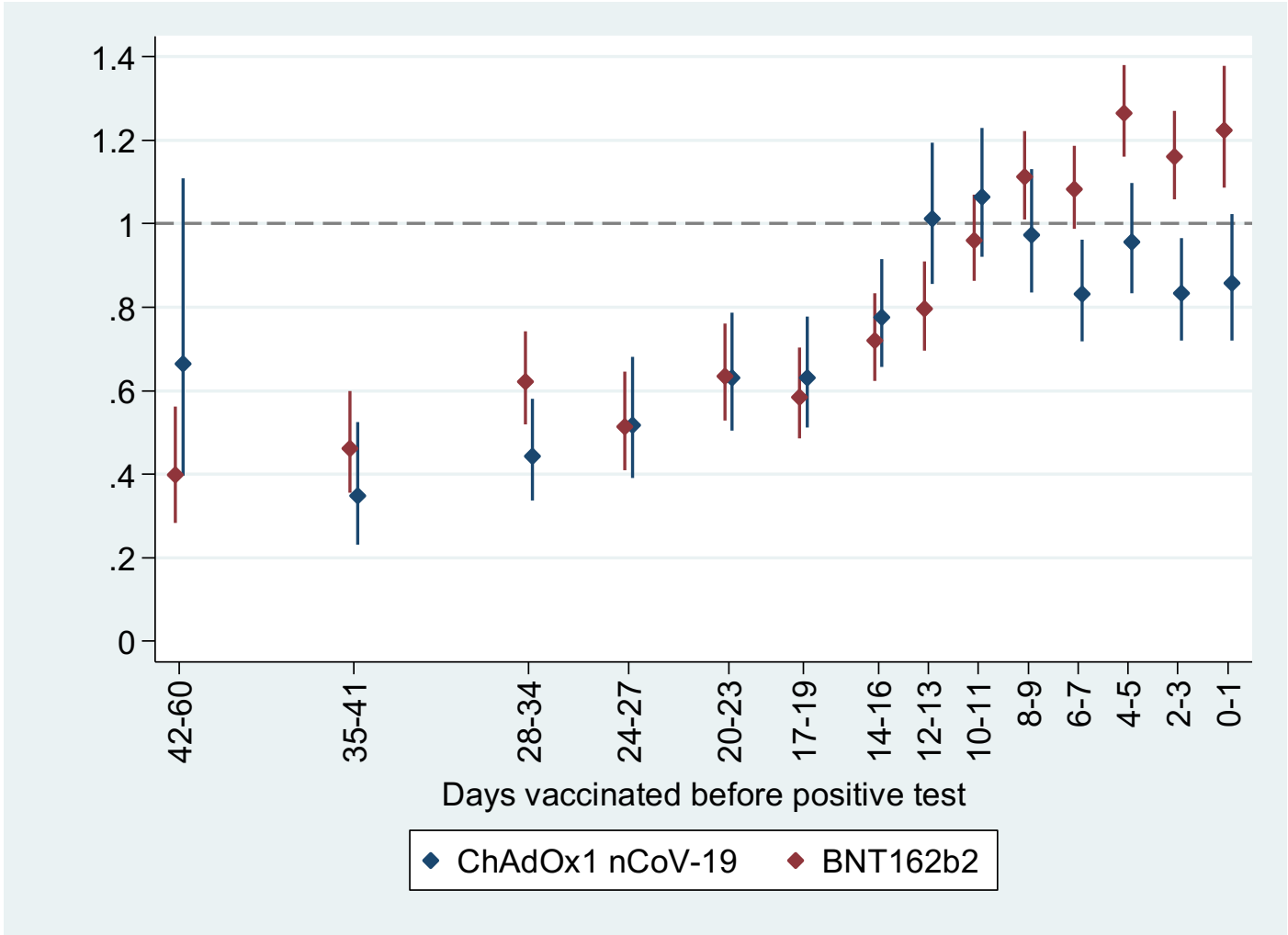
Figure 1. Odds ratios and 95% confidence intervals for contacts becoming a secondary case if the index case was vaccinated with ChAdOx1 nCoV-19 or BNT162b2 21 days or more before testing positive, vs. contacts where the index case was not vaccinated. Results by age of index case and contact from multivariable logistic regression.



Vaccination timing

Figure 2 shows odds ratios for contacts in which the index case had been vaccinated according to the timing of vaccination, compared to households where the index case was not vaccinated. This analysis also includes households where the index case was vaccinated between 0 and 20 days before testing positive, which due to the timing of the rollout and data under consideration, are a larger group than those vaccinated 21+days before testing positive.

Figure 2. Odds ratios for contacts becoming a secondary case according to vaccination timing of the index case (days before testing positive) by type of vaccination, vs. contacts where the index case was not vaccinated. Results from multivariable logistic regression.



The results show that contacts of vaccinated cases have lower odds of being secondary cases if the index case was vaccinated 14 days or more before testing positive after controlling for calendar week, but this protective effect diminishes sharply if vaccination occurs closer to the positive test date. Of note however is that estimates diverge for the 2 vaccines: where index cases are recently vaccinated (less than 10 days before testing positive), odds of being a secondary case are lower for ChAdOx1 nCoV-19, but higher for BNT162b2. Supplementary materials S2 show odds ratios of becoming a secondary case according to vaccination timing for different subgroups and time periods, to explore this further. This suggests that odds of transmission were lower in later calendar weeks for index cases receiving either vaccine compared to unvaccinated cases, suggesting an effect of timing as case rates declined. The pattern among recently vaccinated was also seen in the groups of working age (16-39 and 40-59 years) with sparse data for those age over 60.

Estimated effects based on vaccine timing

Table 3 shows estimated ORs comparing households where the index case was vaccinated 21-35 days before testing positive with households where the index case was vaccinated 1-10 days before testing positive (with the same vaccine type). The adjusted ORs from multivariable logistic regression indicated a halving in the odds of contacts becoming secondary cases if the index case was vaccinated with either ChAdOx1 nCoV-19 or BNT162b2 21-35 days before testing positive. The matched case-control analysis gave slightly attenuated results; as more matching variables were included the estimated effect for ChAdOx1 nCoV-19 became slightly weaker and that for BNT162b2 slightly stronger, but less than half the cases could be matched on the larger set of covariates, and the confidence intervals for ChAdOx1 nCoV-19 were wide. A similar pattern to the results was seen in the stratified cohort analysis; and using the full set of covariates resulted in a very large number of strata (9,825 for ChAdOx1 nCoV-19 and 16,820 for BNT162b2), the majority of which could not be included in the analysis due to there being no secondary cases within the strata.

Table 3. Estimated odds ratios for contacts being a secondary case according to vaccination of the index case 21-35 vs. 1-10 days before the index case tested positive; multivariable logistic regression, matched case-control and stratified cohort designs. The *N* column is the sample size, except for the matched case-control, which is the number of matched secondary cases. The percentage is the proportion of all available data that could be used in the model (either matched, or having usable strata).

	Vaccine	OR (95% CI)	N or cases	% of data
Logistic regression				
	ChAdOx1 nCoV-19	0.53 (0.44, 0.63)	13169	100.0%
	BNT162b2	0.49 (0.44, 0.56)	25688	100.0%
Matched case-control				
1: Age of index case and contact, week of index case vaccination	ChAdOx1 nCoV-19	0.57 (0.46, 0.70)	1218	99.4%
	BNT162b2	0.55 (0.48, 0.64)	2930	99.8%
2: as (1) plus: Sex of index case and contact	ChAdOx1 nCoV-19	0.56 (0.45, 0.70)	1194	97.5%
	BNT162b2	0.56 (0.48, 0.64)	2909	99.0%
3: as (2) plus: household type	ChAdOx1 nCoV-19	0.57 (0.45, 0.71)	1032	84.2%
	BNT162b2	0.50 (0.42, 0.58)	2705	92.1%
4: as (3) plus: IMD	ChAdOx1 nCoV-19	0.53 (0.41, 0.69)	767	62.6%

	Vaccine	OR (95% CI)	N or cases	% of data
	BNT162b2	0.50 (0.42, 0.59)	2264	77.1%
	ChAdOx1 nCoV-19	0.65 (0.49, 0.87)	668	54.5%
5: as (3) plus: region				
	BNT162b2	0.49 (0.41, 0.59)	1992	67.8%
	ChAdOx1 nCoV-19	0.67 (0.46, 0.99)	386	31.5%
5: as (3) plus: region and IMD				
	BNT162b2	0.45 (0.35, 0.58)	1239	42.2%
Stratified cohort				
1: Age of index case and contact, week of index case vaccination	ChAdOx1 nCoV-19	0.55 (0.46, 0.65)	12296	93.4%
	BNT162b2	0.52 (0.46, 0.58)	24937	97.1%
2: as (1) plus: Sex of index case and contact	ChAdOx1 nCoV-19	0.55 (0.46, 0.66)	10397	79.0%
	BNT162b2	0.51 (0.45, 0.58)	22843	88.9%
3: as (2) plus: household type	ChAdOx1 nCoV-19	0.52 (0.43, 0.63)	6755	51.3%
	BNT162b2	0.50 (0.44, 0.57)	17453	67.9%
4: as (3) plus: IMD	ChAdOx1 nCoV-19	0.54 (0.43, 0.68)	3362	25.5%
	BNT162b2	0.49 (0.42, 0.57)	10808	42.1%

	Vaccine	OR (95% CI)	N or cases	% of data
5: as (3) plus: region	ChAdOx1 nCoV-19	0.62 (0.48, 0.80)	2565	19.5%
	BNT162b2	0.47 (0.40, 0.55)	8783	34.2%
5: as (3) plus: region and IMD	ChAdOx1 nCoV-19	0.77 (0.53, 1.12)	1044	7.9%
	BNT162b2	0.43 (0.35, 0.55)	3841	15.0%

Discussion

These results show that the likelihood of household transmission is 40-50% lower for households in which the index cases are vaccinated 21 days or more prior to testing positive (compared to no vaccination), with similar effects for both ChAdOx1 nCoV-19 and BNT162b2 vaccines. Results persisted after adjustment for measured covariates. This effect on onward transmission in the household was particularly apparent for index cases aged less than 70 years. A matched case-control analysis also demonstrated similarly reduced odds ratios for secondary infections in household contacts.

The results on timing of vaccination indicate that the reduction in transmission can be detected at 14 days after vaccination, which is consistent with the timing of effective protection from infection for the vaccinated individual (18).

We used a definition of vaccination status of the index case as having been vaccinated 21 days or more prior to testing, as a summary measure for both vaccines. Three different analytical approaches (logistic regression, matched case-control and stratified cohort) compared index cases vaccinated 21-35 days before a positive test with index cases

vaccinated 1-10 days before positive test; all 3 methods showed reductions in transmission for vaccination 21-35 days before a positive test with both vaccines in keeping with their previous ORs. These results lend confidence to the overall conclusion that vaccination reduces transmission, as the comparison is restricted to index cases that have received a particular vaccine, varying only in the timing of vaccination before testing positive.

To understand observed differences between BNT162b2 and ChAdOx1 nCoV-19 in proportions of secondary cases for index cases who became cases within a week of vaccination, further analysis by age of index case, and contact, calendar week of positive test in index case and vaccination (Supplementary Material S2) suggests underlying differences in the groups, which are not accounted for by measured covariates or differences in the vaccine. This is consistent with reported initial administration in social care workers focusing on BNT162b2 (17) and the early phase of the study period being influenced by high case rates.

These findings provide emerging evidence that receipt of at least one dose of either vaccine reduces transmission of SARS-CoV-2 from a diagnosed case to other persons in the household setting. Currently there is limited published evidence available; Shah *et al* reported reduced risks of infection in household contacts of healthcare workers who received the same vaccines in Scotland (19). However, this study was limited to index cases of working age, specifically health-care workers who may have a different risk of exposure, whereas the analysis presented here represents a wider cross-section of the population who received these vaccines. Therefore, our study can be considered to demonstrate the wider impacts of the vaccination programme in the community, to include those who were vaccinated due to older age and underlying conditions.

Most of the vaccinated index cases (93%) in our analysis had received just one dose of vaccine and it will be important to assess if there are any further reduction in transmissibility from receiving a second dose of vaccine when such data become available. Further

comparisons will also be made to other surveillance data on household transmission, such as the HOCO study (20).

Limitations

The HOSTED dataset only has information on diagnosed secondary cases; studies with active follow-up and serological testing have shown higher rates of household transmission (21). Our data cannot identify asymptomatic cases. However, case ascertainment is unlikely to be biased towards either the contacts of vaccinated or unvaccinated cases. Additionally, differences in transmission according to the timing of vaccination in index cases, and comparison of vaccination more versus less than 3 weeks before testing positive in index cases lends confidence to the overall results. It is reassuring that a similar effect was observed in a different dataset (19).

Our definition of 'secondary' cases may have led to the inclusion of some cases that were in fact co-primary. As the incubation period for SAR-CoV2 is thought to be two-to-14 days (22,23), we chose a threshold of 2 days between the specimen dates of the index and secondary cases to offset the risks of misclassifying cases as either co-primary or as secondary. Previous sensitivity analyses using a cut-off of 4 days found little effect on results or on the multivariable model (24). We have also made the implicit assumption that 2 (or more) cases occurring in a household within 2-to-14 days represents household transmission when it also plausible that they are 2 independent community acquired infections. However, the data from this analysis refer to a time in which England was in lock-down and therefore the scope for acquiring infection outside the household should be reduced.

We restricted our analysis to household contacts of index cases who tested positive through community testing (pillar 2), whereas individuals tested in pillar 1 consist of those tested in hospital and healthcare workers. Hospitalised cases may present markedly different exposure risks to their household contacts: severe cases may be more infectious; however, once hospitalised, their contacts would not be exposed to further risk of infection. Data on

hospitalisation is currently limited in this dataset due to reporting delays and because hospitalisation is only recorded in the HOSTED dataset if it occurs on or after the positive test date. It is not currently possible to specifically identify healthcare workers in Pillar 1 case data, to aid further characterisation. Further work is required to understand the exposure risks for contacts of cases tested in pillar 1, and how these may be affected by vaccination.

Although the main group receiving vaccinations in the time period was the over 70s, the number of index cases in this age group was small, and vaccinated index cases aged 70+ smaller still, due to the effectiveness of the vaccines. Further, household contacts aged 70+ who have not received the vaccination, when the index case has been vaccinated, are also comparatively rare, due to the success of the vaccine rollout programme. These analyses are thus based largely on individuals aged less than 60, who will have been vaccinated due to underlying health conditions, being carers of vulnerable individuals, or because they are social care workers. Again, doubts around the comparability of vaccinated and unvaccinated index cases are assuaged by the results on the timing of vaccination in vaccinated individuals. These findings are likely to be generalisable to other high income countries using these 2 vaccines in national vaccination programmes.

Conclusions

In addition to the direct effects of preventing cases and reducing severity, we have shown that both the ChAdOx1 nCoV-19 and BNT162b2 vaccines are associated with reduced likelihood of household transmission by 40-50% from individuals diagnosed with COVID-19 after vaccination, highlighting important wider benefits to close contacts. While this analysis was primarily intended to understand impacts on transmission to household contacts rather than those outside the household, the former are consistently identified as being at high risk for secondary infection. Therefore, these results could also have implications for transmissibility in other settings with similar transmission risks. These would need to be considered in future pandemic modelling to fully capture the impact of the vaccination programme and to inform public health strategies and public communication going forward.

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Ethics approval

The HOSTED surveillance system was reviewed and approved by the PHE Research Ethics Governance Group. The data was collected and linked by NHS Digital. The data was processed lawfully under GDPR Article 6(1)e and 9(2)i and shared under Regulation 3(4) of the Health Service (Control of Patient Information) Regulations 2002.

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Data Availability Statement

The data underlying this article cannot be shared publicly due to the legal and policy controls placed on data used as part of the government's response to the Covid19 pandemic.

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Conflict of interest statement

None declared

Supplementary material S1 – Multivariable logistic regression for outcome of household contact becoming a secondary case

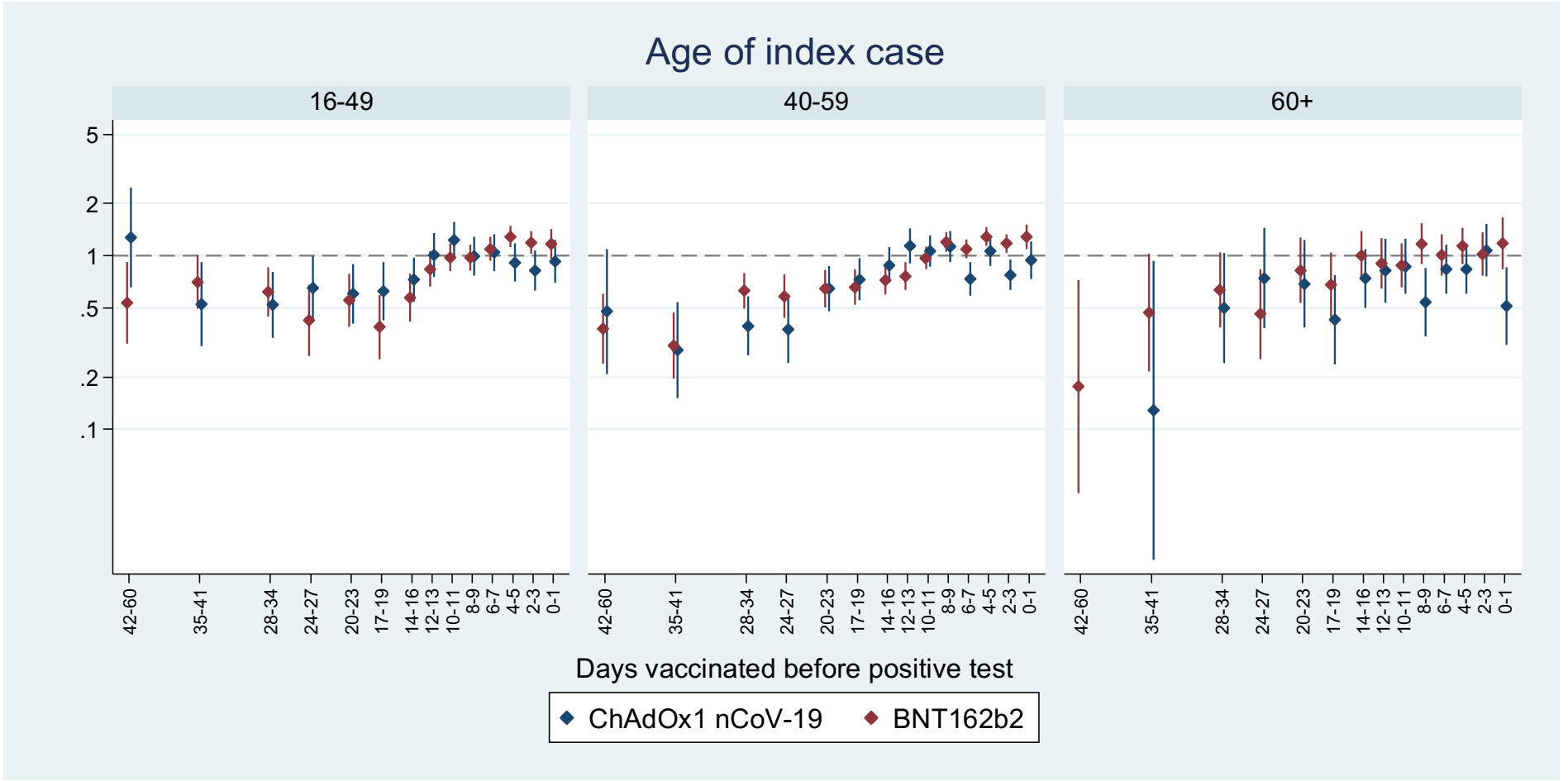
	Odds Ratio	LCI	UCI	p-value
Age of index case				
16-29	1 (base)			
30-39	1.33	1.30	1.37	<0.001
40-49	1.72	1.68	1.77	<0.001
50-59	1.98	1.93	2.04	<0.001
60-69	2.09	2.01	2.16	<0.001
70-79	2.00	1.86	2.14	<0.001
80+	2.00	1.75	2.28	<0.001
Age of contact				
0-15	1 (base)			
16-29	1.67	1.63	1.71	<0.001
30-39	1.76	1.72	1.81	<0.001
40-49	2.13	2.08	2.18	<0.001
50-59	2.45	2.38	2.51	<0.001
60-69	2.21	2.14	2.29	<0.001
70-79	1.82	1.73	1.92	<0.001
80+	1.67	1.54	1.82	<0.001
Sex of index case				
Male	1 (base)			
Female	0.99	0.97	1.01	0.175
Sex of contact				
Male	1 (base)			
Female	1.27	1.25	1.28	<0.001
Index case date				
04 Jan - 10 Jan	1 (base)			
11 Jan - 17 Jan	0.93	0.91	0.96	<0.001

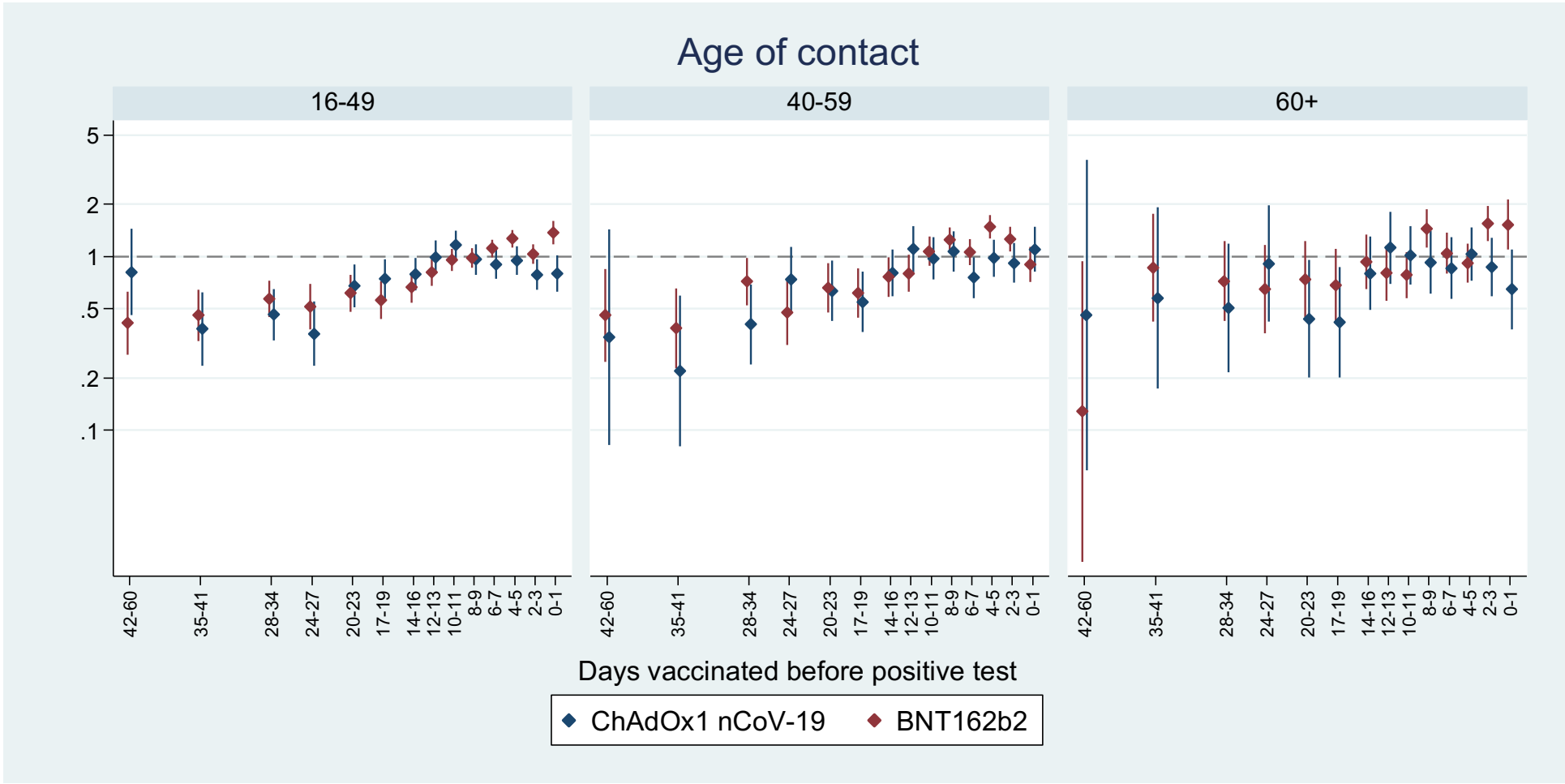
	Odds Ratio	LCI	UCI	p-value
18 Jan - 24 Jan	0.87	0.85	0.89	<0.001
25 Jan - 31 Jan	0.82	0.80	0.85	<0.001
01 Feb - 07 Feb	0.85	0.82	0.88	<0.001
08 Feb - 14 Feb	0.90	0.86	0.93	<0.001
15 Feb - 21 Feb	0.83	0.79	0.87	<0.001
22 Feb - 28 Feb	0.76	0.72	0.81	<0.001
IMD quintile				
1	1 (base)			
2	1.06	1.03	1.09	<0.001
3	1.12	1.09	1.15	<0.001
4	1.19	1.16	1.22	<0.001
5	1.18	1.15	1.22	<0.001
Region				
East Midlands	1.09	1.05	1.13	<0.001
East of England	1.04	1.01	1.08	0.023
London	0.78	0.76	0.80	<0.001
North East	1.24	1.18	1.30	<0.001
North West	1.13	1.10	1.17	<0.001
South East	1 (base)			
South West	0.95	0.91	0.99	0.020
West Midlands	1.14	1.10	1.18	<0.001
Yorkshire and The Humber	1.14	1.09	1.18	<0.001
Household type				
Adult pair/couple	1 (base)			
Older pair/couple	1.04	0.98	1.10	0.171
HH with children, 2-4	1.21	1.17	1.25	<0.001
HH with children, 5-7	0.79	0.76	0.81	<0.001
HH with children, 8-10	0.48	0.45	0.51	<0.001

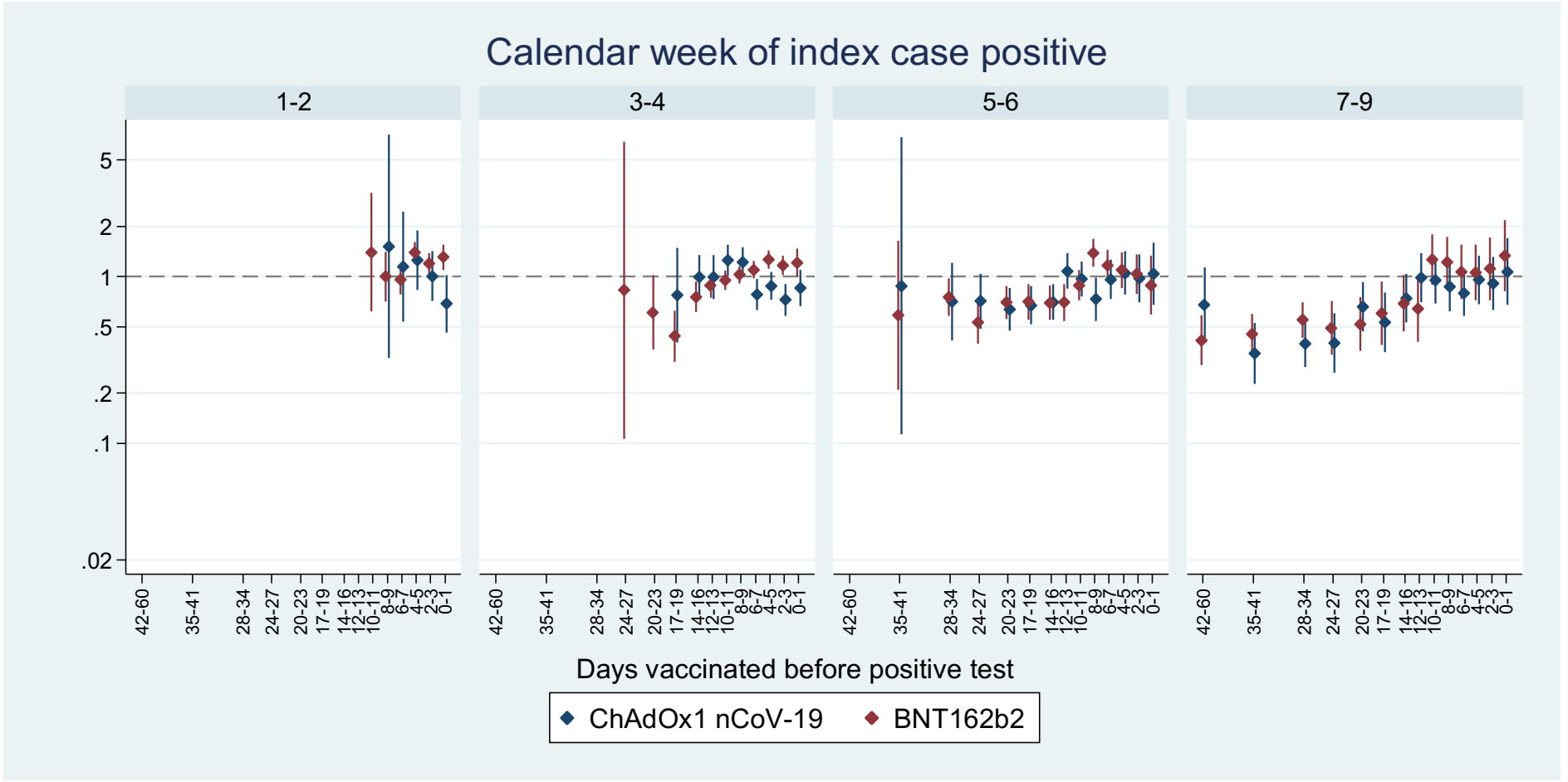
	Odds Ratio	LCI	UCI	p-value
Multi-gen HH, 3-4	0.79	0.73	0.86	<0.001
Multi-gen HH, 5-7	0.71	0.68	0.75	<0.001
Multi-gen HH, 8-10	0.54	0.51	0.58	<0.001
Adult only, 3-4	0.72	0.70	0.74	<0.001
Adult only, 5-7	0.53	0.51	0.55	<0.001
Adult only, 8-10	0.25	0.22	0.28	<0.001
Vaccination of index case				
Not vaccinated	1 (base)			
ChAdOx1 nCoV-19	0.52	0.43	0.62	<0.001
BNT162b2	0.54	0.47	0.62	<0.001

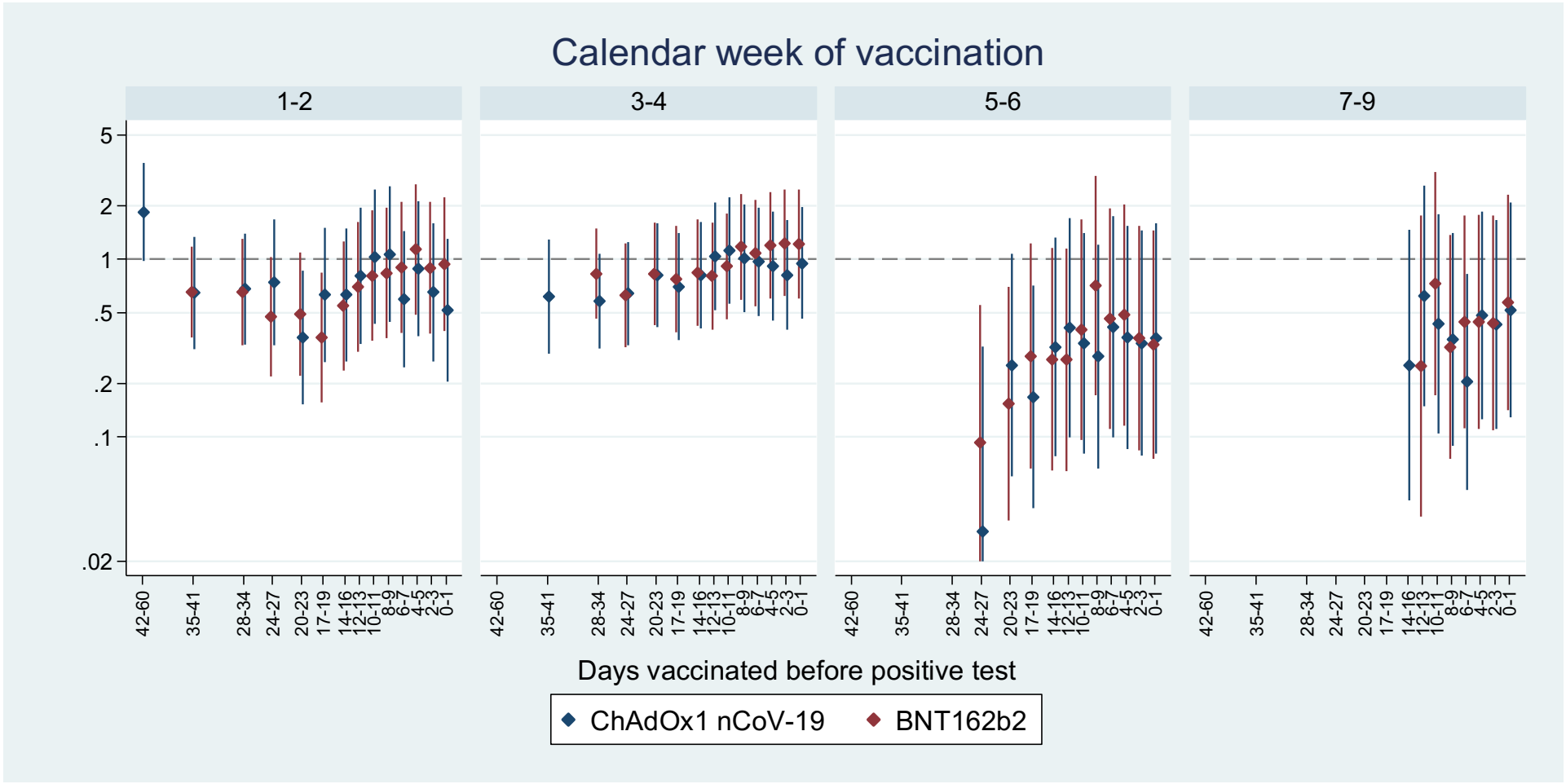
Supplementary Material S2

The following plots show odds ratios for contacts becoming a secondary case according to vaccination timing of the index case (days before testing positive) by type of vaccination, vs. contacts where the index case was not vaccinated as in Figure 1 of the main paper. Plots are by different subgroups, with results from the multivariable logistic regression model used in the main paper, stratified by various subgroups.


Age of index case
16-49
40-59
60+
Odds ratio
5
2
1
.5
.2
.1
42-60
35-41
28-34
24-27
20-23
17-19
14-16
12-13
10-11
8-9
6-7
4-5
2-3
0-1
Days vaccinated before positive test
ChAdOx1 nCoV-19
BNT162b2


Age of contact
16-49
40-59
60+
Odds ratio
5
2
1
.5
.2
.1
42-60
35-41
28-34
24-27
20-23
17-19
14-16
12-13
10-11
8-9
6-7
4-5
2-3
0-1
Days vaccinated before positive test
ChAdOx1 nCoV-19
BNT162b2


Calendar week of index case positive
1-2
3-4
5-6
7-9
Odds ratio
5
2
1
.5
.2
.1
.02
42-60
35-41
28-34
24-27
20-23
17-19
14-16
12-13
10-11
8-9
6-7
4-5
2-3
0-1
Days vaccinated before positive test
ChAdOx1 nCoV-19
BNT162b2



Note: the comparison group, unvaccinated index cases, do not have a vaccination date; therefore a comparable date for grouping was imputed based on the average interval between vaccination and testing positive in vaccinated index cases, which was calculated separately for each week of vaccination.