

# 1 The impact of SARS-CoV-2 vaccination on Alpha & Delta variant 2 transmission

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**NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.**

## 18 Abstract

19

### 20 Background

21 Pre-Delta, vaccination reduced transmission of SARS-CoV-2 from individuals infected despite  
22 vaccination, potentially via reducing viral loads. While vaccination still lowers the risk of  
23 infection, similar viral loads in vaccinated and unvaccinated individuals infected with Delta  
24 question how much vaccination prevents onward transmission.

25

### 26 Methods

27 We performed a retrospective observational cohort study of contacts of SARS-CoV-2-  
28 infected index cases using contact testing data from England. We used multivariable logistic  
29 regression to investigate the impact of index case and contact vaccination on transmission,  
30 and how this varies with Alpha and Delta variants (classified using S-gene  
31 detection/calendar trends) and time since second vaccination.

32

### 33 Results

34 51,798/139,164(37.2%) contacts tested were PCR-positive. Two doses of BNT162b2 or  
35 ChAdOx1 vaccines in Alpha variant index cases independently reduced PCR-positivity in  
36 contacts (aOR, adjusted odds ratio vs. unvaccinated=0.18[95%CI 0.12-0.29] and 0.37[0.22-  
37 0.63] respectively). The Delta variant attenuated vaccine-associated reductions in  
38 transmission: two BNT162b2 doses reduced Delta transmission (aOR=0.35[0.26-0.48]), more  
39 than ChAdOx1 (aOR=0.64[0.57-0.72]; heterogeneity  $p < 0.001$ ). Variation in viral load (Ct  
40 values) explained only a modest proportion of vaccine-associated transmission reductions.

41 Transmission reductions declined over time since second vaccination, for Delta reaching  
42 similar levels to unvaccinated individuals by 12 weeks for ChAdOx1 and attenuating  
43 substantially for BNT162b2. Protection from vaccination in contacts also declined in the 3  
44 months after second vaccination.

45

46 **Conclusions**

47 Vaccination reduces transmission of Delta, but by less than the Alpha variant. The impact of  
48 vaccination decreased over time. Factors other than PCR-measured viral load are important  
49 in vaccine-associated transmission reductions. Booster vaccinations may help control  
50 transmission together with preventing infections.

51

## 52 Introduction

53 SARS-CoV-2 vaccines have been shown in randomised controlled trials<sup>1-3</sup> and real-world  
54 population studies<sup>4,5</sup> to prevent infection and adverse outcomes from several SARS-CoV-2  
55 variants including Alpha (B.1.1.7) and Delta (B.1.617.2).<sup>6-8</sup>

56

57 Vaccination also potentially prevents onward transmission by at least two mechanisms.  
58 Firstly, by reducing symptomatic and asymptomatic infections and therefore the number of  
59 infectious individuals, and secondly via reduced onward spread from those who become  
60 infected despite vaccination. Household studies have demonstrated vaccination reduces  
61 onward transmission of the Alpha variant from those infected despite vaccination in the  
62 UK,<sup>9</sup> Israel<sup>10,11</sup> and Finland.<sup>12</sup> One hypothesised mechanism is lower viral loads observed in  
63 post-vaccination Alpha infections<sup>7,13</sup> compared in unvaccinated individuals, as viral load is  
64 associated with the likelihood of infection in contacts.<sup>14,15</sup>

65

66 However, viral loads in Delta variant infections occurring after vaccination are similar in  
67 vaccinated and unvaccinated individuals,<sup>8,16</sup> although the duration of viral shedding may be  
68 reduced.<sup>17,18</sup> This questions whether vaccination can control Delta spread as effectively as  
69 Alpha, and whether, with increased transmissibility,<sup>19</sup> this explains the rapid global  
70 dissemination of Delta despite rising vaccination coverage.

71

72 We use national contact testing data from England to investigate the impact of vaccination  
73 on onward transmission of SARS-CoV-2, and how this varies with Alpha and Delta variants

74 and time since second vaccination. We also investigate how much reductions in  
75 transmission after vaccination are explained by variation in PCR cycle threshold (Ct) values.

76

## 77 [Methods](#)

### 78 [Setting and variants](#)

79 We performed a retrospective observational cohort study of contacts of symptomatic and  
80 asymptomatic SARS-CoV-2-infected index cases. Data were obtained from the national  
81 contact tracing and testing service in England, NHS Test and Trace. Contacts were eligible for  
82 inclusion if they accessed NHS Test and Trace PCR testing 1-10 days after the index case's  
83 PCR test (typically following symptoms, but also after positive asymptomatic antigen  
84 screening tests), i.e. including contact pairs where the index case was the most likely source  
85 for any infection in the contact.<sup>15</sup> Only index cases with PCR tests performed by three  
86 national "lighthouse" laboratories (Milton Keynes, Alderley Park, Glasgow) were included, as  
87 these tests used the same standardised workflow and PCR assay (Thermo Fisher TaqPath,  
88 assessing for S gene, N gene and ORF1ab targets). Contacts could be tested by any  
89 community/hospital laboratory reporting results to NHS Test and Trace. Vaccination status  
90 in cases and contacts was obtained from National Immunisation Management Service (see  
91 Supplement).

92

93 Contacts of index cases tested between 01-January-2021 and 31-July-2021 were included as  
94 follows. Index cases were classified as the Alpha (B.1.1.7) variant based on S-gene target  
95 failure (SGTF), while this was considered a reliable proxy for Alpha, namely to 06-June-2021  
96 (after which <5% cases had SGTF). From 10-May-2021 national spread of Delta meant that

97 >98% of sequenced cases were either due to the Alpha or Delta variants,<sup>19</sup> such that we  
98 used detection of S-gene on or after 10-May-2021 as a proxy for Delta (see Supplement).

99

100 We restricted our analysis to contacts undergoing testing, excluding untested contacts, to  
101 control as much as possible for biases related to health-seeking behaviour (including  
102 differences before and after vaccination), access to testing, and case ascertainment.<sup>20</sup>

103

#### 104 [Statistical analysis](#)

105 We used multivariable logistic regression to investigate how onward transmission, i.e.,  
106 SARS-CoV-2 PCR-positive tests in contacts, varied with index case vaccination status. Index  
107 case vaccination status was defined using administrative classifications as: unvaccinated,  
108 partially vaccinated (from day of first vaccine to 13 days after second vaccine), or fully  
109 vaccinated ( $\geq 14$  days after second vaccine), further considering whether vaccination was  
110 AstraZeneca ChAdOx1 or Pfizer-BioNTech BNT162b2. We also investigated how onward  
111 transmission varied with Alpha vs. Delta index cases and whether any effects varied by  
112 vaccine by including pre-specified interaction terms. We additionally included a model term  
113 for time since 14 days after second BNT162b2 or ChAdOx1 vaccine to estimate the effect of  
114 time since second vaccine.

115

116 We adjusted for the following additional covariates: contact event type; index case factors -  
117 age, sex, and symptom status; contact factors - age, sex, vaccination status and time since  
118 vaccination (as above); local deprivation, local SARS-CoV-2 incidence, and calendar time (to  
119 capture changes in behaviour/social distancing, the likelihood of acquisition from a third  
120 party, population-wide vaccine uptake, and the percentage of unvaccinated people

121 previously infected) (Table S1). We used natural cubic splines and log transformation to  
122 account for non-linearity and tested for interactions (see Supplement).

123

124 We refitted models including index case Ct values to investigate whether the effect of index  
125 case vaccination status was explained by viral load (approximated Ct value<sup>21</sup>).

126

## 127 Ethics

128 The study was performed as public health surveillance and NHS Test and Trace program  
129 quality assurance, under Section 251 of the NHS Act 2006 with approvals from Public Health  
130 England (PHE), the Department of Health and Social Care and NHS Test and Trace. PHE's  
131 Research Ethics and Governance Group (PHE's Research Ethics Committee) reviewed the  
132 study protocol and confirmed compliance with all regulatory requirements. As no regulatory  
133 or ethical issues were identified, it was agreed that full ethical review was not needed, and  
134 the protocol was approved.

135

## 136 Results

137 151,821 contacts of 99,597 index cases underwent PCR testing between 02-January-2021  
138 and 02-August-2021. 12,657 contacts were excluded with incomplete data (8.3%, see  
139 Supplement). Of the remaining 139,164 contacts (95,716 index cases), 51,798(37.2%) tested  
140 PCR-positive. The median(IQR)[range] index case and contact ages were 38(26-50)[0-102]  
141 and 38(23-50)[0-104] years respectively. 50,356(53%) index cases and 77,277(56%) contacts  
142 were female (see Table S1-S2 for details by case and contact vaccine status). Contact events

143 were predominantly within households (97,387;70%), but also in household visitors  
144 (14,066;10%), at events and activities (14,270;10%) and at work/education (13,441;10%).

145

#### 146 [Index case vaccination and onward transmission](#)

147 27,666/55,977(49%) contacts of unvaccinated index cases tested PCR-positive, as did  
148 5,256/14,398(37%) and 9,623/36,085(27%) contacts of partially ChAdOx1 and BNT162b2  
149 vaccinated cases, and 7,559/25,422(30%) and 1,694/7,282(23%) contacts of fully ChAdOx1  
150 and BNT162b2 vaccinated cases. For index cases vaccinated twice with BNT162b2 or  
151 ChAdOx1 the median(IQR) days from second vaccine to an Alpha variant PCR-positive test  
152 was 41(26-62) or 27(18-43) respectively and 89(69-110) and 50(34-69) for Delta.

153

154 In a multivariable model (Tables 1, S4), BNT162b2 vaccination in Alpha variant index cases  
155 independently reduced PCR-positive results in contacts, with two doses (aOR, adjusted odds  
156 ratio at 14 days post-second vaccine vs. unvaccinated=0.18[95%CI 0.12-0.29]) reducing  
157 onward transmission more than one (aOR=0.74[0.70-0.80]). There was weak evidence that  
158 ChAdOx1 was less effective than BNT162b2 at preventing transmission after one (aOR vs.  
159 unvaccinated=0.82[0.76-0.88], p=0.11 vs BNT162b2) and two doses (aOR=0.37[0.22-0.63],  
160 p=0.085 vs BNT162b2).

161

162 The Delta variant was associated with increased onward transmission vs. Alpha for  
163 symptomatic index cases (aOR=1.30[1.10-1.54]) and to a greater extent for asymptomatic  
164 index cases (aOR=2.14[1.75-2.60]). Post-second dose vaccine-associated reductions on  
165 onward transmission were also attenuated with Delta, for both BNT162b2 by 1.9-fold  
166 (aOR=1.93[1.25-2.99]) and ChAdOx1 by 1.7-fold (aOR=1.71[1.01-2.90]). This resulted in two



167 BNT162b2 doses reducing onward transmission of Delta by a greater extent than ChAdOx1  
168 (aOR=0.35[0.26-0.48] vs aOR=0.64[0.57-0.72], respectively, heterogeneity  $p<0.001$ ).

169

#### 170 [Vaccination in contacts](#)

171 The estimated effect of contact vaccination status does not reflect overall vaccine  
172 effectiveness, as study inclusion was conditional on the contact being tested (typically after  
173 developing symptoms). However, as expected, PCR-positivity was highest in unvaccinated  
174 contacts (34,137/70,370(49%)), followed by those partially vaccinated with ChAdOx1,  
175 (3,401/10,325(33%)) and BNT162b2 (5,809/18,017(32%)); those fully vaccinated with  
176 ChAdOx1 (6,163/27,343(23%)) and BNT162b2 (2,288/13,109(17%)) had the lowest rates. In  
177 a multivariable model (Tables 1, S4), with Alpha contacts fully vaccinated with BNT162b2  
178 had lower rates of PCR-positive tests than ChAdOx1 (aOR at 14 days post second vaccine vs.  
179 unvaccinated=0.06[0.04-0.10] vs. aOR=0.29[0.17-0.49] respectively, heterogeneity  $p<0.001$ ).  
180 With Delta, more BNT162b2 vaccinated contacts tested PCR-positive than with Alpha, but  
181 there was no evidence that PCR-positivity changed in fully ChAdOx1 vaccinated contacts.  
182 Nevertheless, two doses of BNT162b2 remained more effective against Delta than ChAdOx1  
183 (aOR vs. unvaccinated=0.10[0.08-0.13] vs aOR=0.28[0.25-0.32], respectively, heterogeneity  
184  $p<0.001$ ).

185

#### 186 [Duration of protection and transmission reductions](#)

187 Vaccine-associated reductions in onward transmission declined over time since second  
188 vaccination in index cases (Figure 1A, Table S4). Independently of contact vaccination status,  
189 for each doubling of weeks since 14 days after second vaccination in index cases, the odds  
190 of a contact testing PCR-positive increased 1.13-fold (95%CI 1.09-1.17) for ChAdOx1 and

191 1.20-fold (1.10-1.31) for BNT162b2 with no evidence of a difference between vaccines  
192 ( $p=0.19$ ). There was no evidence that fitting different rates by variant improved model fit.  
193 However, higher probabilities of PCR-positive results in contacts 14 days after second  
194 vaccination for Delta vs. Alpha meant that by 12 weeks post second ChAdOx1 dose there  
195 was no evidence that onward Delta transmission rates differed between those not  
196 vaccinated and those having received two ChAdOx1 doses and the impact of BNT162b2 had  
197 also attenuated substantially.

198

199 Although 14 days post second vaccination in contacts, those receiving BNT162b2 vs.  
200 ChAdOx1 were at lower risk of testing positive, the protective effect of vaccination in  
201 contacts waned faster for BNT162b2 than ChAdOx1 (Figure 1B, aOR per doubling of weeks  
202 since 14 days after second vaccination=1.37[95%CI 1.27-1.48] vs. 1.16[1.11-1.21] for  
203 ChAdOx1; heterogeneity  $p=0.002$ ).

204

#### 205 [Other transmission risk factors](#)

206 Multiple other factors were associated with contacts testing positive (Figure 2, Table S4,  
207 Figures S2-S4), including contact event type and index case age, with the highest rates of  
208 PCR-positivity after household contact with index cases aged  $\geq 30$  years and the lowest rates  
209 following contact with index cases  $< 20$  years at work or education (Figure 2A). Contacts in  
210 their 30s, 40s and 70s had the highest rates of positive tests after household contact, while  
211 contacts in their 20s had the highest rates after contact events outside their own home  
212 (Figure 2B). Contacts of index cases of the opposite sex were more likely to test positive,  
213 except for children where contacts of girls were more likely to test positive (Figure 2C). Male  
214 contacts were more likely than female contacts to be infected outside the home (Figure S2).

215 Case-contact pairs of similar ages were most likely to test positive, particularly with  
216 increasing age (Figure 2D). Contacts of asymptomatic index cases were less likely to test  
217 positive (aOR for Alpha=0.28[95%CI 0.26-0.30], Delta=0.61[0.50-0.73]) likely related to both  
218 lower viral loads (Figure 3) and symptoms. Contacts living in more deprived areas and areas  
219 with higher SARS-CoV-2 incidence (Figure S3) were more likely to test positive. Positivity  
220 also varied by calendar time (Figure S4).

221

#### 222 [Extent of vaccine impact on transmission explained by viral load](#)

223 Consistent with previous reports, vaccination with BNT162b2 or ChAdOx1 was associated  
224 with lower viral loads in Alpha index cases at the time of their positive test, e.g. after two  
225 vaccinations in the presence of symptoms, median Ct values (IQR) were 27.9(19.7-32.8) and  
226 25.5(18.1-33.0) vs. 18.4(15.8-22.8) if unvaccinated. However, Delta variant infections had  
227 similar viral loads independent of vaccination status (Figure 3), and higher viral loads than  
228 Alpha in both symptomatic and asymptomatic infections.

229

230 We investigated if adjusting for index case Ct values could explain the attenuated reductions  
231 in onward transmission after vaccination seen with the Delta variant. Estimates, adjusted for  
232 Ct value, of the impact of index case vaccination status and variants showed variation in  
233 measured Ct value accounted for only a modest proportion of the impact of vaccination  
234 overall (Figure 4A). This potentially explains why vaccination still reduces onward  
235 transmission of Delta despite Ct values at the index positive test being similar regardless of  
236 vaccination status. Higher viral loads (lower Ct values) were independently associated with  
237 increased transmission for both Alpha and Delta, but with a greater reduction in  
238 transmission of Alpha vs. Delta at lower viral loads (Figure 4B).

239

## 240 Discussion

241 Using large-scale contact tracing data, we show that BNT162b2 and ChAdOx1 vaccination  
242 both reduce onward transmission of SARS-CoV-2 from individuals infected despite  
243 vaccination. However, reductions in transmission are lower for both vaccines for the Delta  
244 variant compared to Alpha. Vaccines continue to provide protection against infection with  
245 Delta, but to a lesser degree than with Alpha, particularly considering symptomatic  
246 infections or infections with moderate/high viral loads.<sup>8</sup> Therefore, Delta erodes vaccine-  
247 associated protection against transmission by both making infection more common and  
248 increasing the likelihood of transmission from vaccinated individuals who become infected.

249

250 It has been hypothesised that vaccines reduce onward transmission from infected  
251 vaccinated individuals by reducing viral loads, as higher viral loads are associated with  
252 transmission.<sup>14,15</sup> Therefore, it is perhaps surprising we found that most of the effect of  
253 vaccines persisted after adjusting for Ct values, i.e., factors other than PCR-measured viral  
254 load at diagnosis are important in vaccine-associated transmission reductions. The single  
255 measured Ct value only approximates viral load at the time of transmission, as viral loads  
256 are dynamic over time.<sup>22</sup> Hence, observed viral loads may not be representative of viral  
257 loads at transmission, however, the strong relationship between measured Ct values and  
258 risk of onward transmission argues against this<sup>15</sup> (replicated here, Figure 4B). Therefore, it is  
259 possible vaccination acts by facilitating faster clearance of viable infectious virions,<sup>17,18</sup> but  
260 leaving damaged ineffective virions behind that still contain PCR-detectable RNA. This may

261 mean antigen assays have advantages in predicting the risk of onward transmission in those  
262 vaccinated, but this needs further study.

263

264 We found that index cases infected with the Delta variant and vaccinated with BNT162b2  
265 had lower odds of having PCR-positive contacts compared to index cases receiving  
266 ChAdOx1, with potentially insufficient power to resolve differences for Alpha. Contacts  
267 vaccinated twice with BNT162b2 also had lower rates of Alpha and Delta infections than  
268 those vaccinated with ChAdOx1.

269

270 Protection against onward transmission waned within 3 months post second vaccination.

271 For Alpha this still left good levels of protection against transmission, but for Delta this

272 eroded much of the protection against onward transmission, particularly for ChAdOx1,

273 which by 3 months post second vaccine had no evidence of difference in transmission

274 compared to that seen in unvaccinated individuals. “Waning” of protective behaviour over

275 time may also underlie some of the differences seen, with vaccination facilitating reduced

276 social distancing and mask wearing. However, reductions in antibody levels<sup>23</sup> and vaccine

277 effectiveness<sup>8</sup> over time suggest biological explanations for increasing transmission over

278 time are likely important. Additionally, some of the observed decline may be attributable to

279 the fact that those clinically vulnerable with weaker immune systems were vaccinated

280 longer ago. We also find that the probability of a contact testing positive increased with

281 time since their second vaccination. Although BNT162b2 provided higher levels of

282 protection for contacts throughout the 3 months post-second vaccine, protection against

283 infection waned faster for BNT162b2 than ChAdOx1, as also seen in a representative UK

284 survey.<sup>8</sup>

285

286 This study has several limitations. We considered only contacts who underwent PCR testing,  
287 to minimise bias introduced by differences in testing behaviour that may occur for multiple  
288 reasons including vaccination of contacts. This means we cannot estimate secondary attack  
289 rates by case and contact vaccination status, and that absolute protective effects of  
290 vaccination on transmission may be under-estimated as vaccine-protected uninfected  
291 contacts may not have sought testing. Our approach is also not likely to eliminate bias,  
292 particularly if test-seeking behaviour is related to perceived vaccine efficacy, given non-  
293 specificity of many symptoms.<sup>24</sup> We did not have sufficient data to consider the impact of  
294 previous infection status, which is also imperfectly ascertained in national testing programs.  
295 It is likely that part of the explanation for the declines over time in the adjusted probability  
296 of contacts testing positive (Figure S4), is increasing prevalence of prior infection in the  
297 unvaccinated group, along with changes in test seeking behaviour and the incidence of  
298 other infections causing similar symptoms.<sup>25</sup> We also had to use SGTF and time as a proxy  
299 for Alpha vs. Delta infection rather than sequencing, which means some low viral load Delta  
300 infections with SGTF may have been misclassified as Alpha, however we restricted the time  
301 period of our dataset to minimise this. As we considered all PCR results in contacts, not just  
302 those tested with assays including an S-gene target, we could not assess SGTF concordance  
303 as supporting evidence for transmission between case-contact pairs. Finally, we did not  
304 have data to adjust for comorbidities; with clinically vulnerable individuals and healthcare  
305 workers vaccinated earlier, this may have partly impacted some of our findings, particularly  
306 on waning over time and differences by vaccine type.

307

308 The Delta variant has spread globally and caused resurgences of infection even in the setting  
309 of high vaccination coverage. Increased onward transmission from individuals who become  
310 infected despite vaccination is an important reason for its spread. Booster vaccination  
311 campaigns being considered and implemented<sup>26</sup> are likely to help control transmission as  
312 well as preventing infections.

313

### 314 Data availability

315 Applications to use the data in this study can be made to NHS Digital's Data Access Request  
316 Service, please see <https://digital.nhs.uk/services/data-access-request-service-dars> for more  
317 details.

318

### 319 Declarations

320 DWE declares lecture fees from Gilead outside the submitted work. No other author has a  
321 conflict of interest to declare.

322

### 323 Funding

324 This study was funded by the UK Government's Department of Health and Social Care. This  
325 work was supported by the National Institute for Health Research Health Protection  
326 Research Unit (NIHR HPRU) in Healthcare Associated Infections and Antimicrobial Resistance  
327 at Oxford University in partnership with Public Health England (PHE) (NIHR200915), and the  
328 NIHR Biomedical Research Centre, Oxford. The views expressed in this publication are those  
329 of the authors and not necessarily those of the NHS, the National Institute for Health

330 Research, the Department of Health or Public Health England. DWE is a Robertson

331 Foundation Fellow and an NIHR Oxford BRC Senior Fellow. ASW is an NIHR Senior

332 Investigator.

333



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- 403

404 Table

Characteristic	Alpha			Delta			Alpha vs Delta		
	aOR	95% CI	p-value	aOR	95% CI	p-value	Interaction OR	95% CI	Interaction p value
<b><i>Impact on onward transmission: Case vaccination status</i></b>									
Unvaccinated	—	—	—	—	—	—	—	—	—
Partial ChAdOx1	0.82	0.76, 0.88	<0.001	0.98	0.90, 1.06	0.99	1.20	1.07, 1.34	0.003
Partial BNT162b2	0.74	0.70, 0.80	<0.001	0.87	0.81, 0.94	0.004	1.17	1.06, 1.30	0.009
Full ChAdOx1	0.37	0.22, 0.63	0.002	0.64	0.57, 0.72	<0.001	1.71	1.01, 2.90	0.045
Full BNT162b2	0.18	0.12, 0.29	<0.001	0.35	0.26, 0.48	<0.001	1.93	1.25, 2.99	0.003
<b><i>Contact vaccination status</i></b>									
Unvaccinated	—	—	—	—	—	—	—	—	—
Partial ChAdOx1	0.89	0.82, 0.97	0.076	0.54	0.50, 0.58	<0.001	0.60	0.54, 0.67	<0.001
Partial BNT162b2	0.69	0.64, 0.75	<0.001	0.58	0.55, 0.61	<0.001	0.83	0.76, 0.92	<0.001
Full ChAdOx1	0.29	0.17, 0.49	<0.001	0.28	0.25, 0.32	<0.001	0.97	0.57, 1.65	0.91
Full BNT162b2	0.06	0.04, 0.10	<0.001	0.10	0.08, 0.13	<0.001	1.64	1.07, 2.51	0.024

405

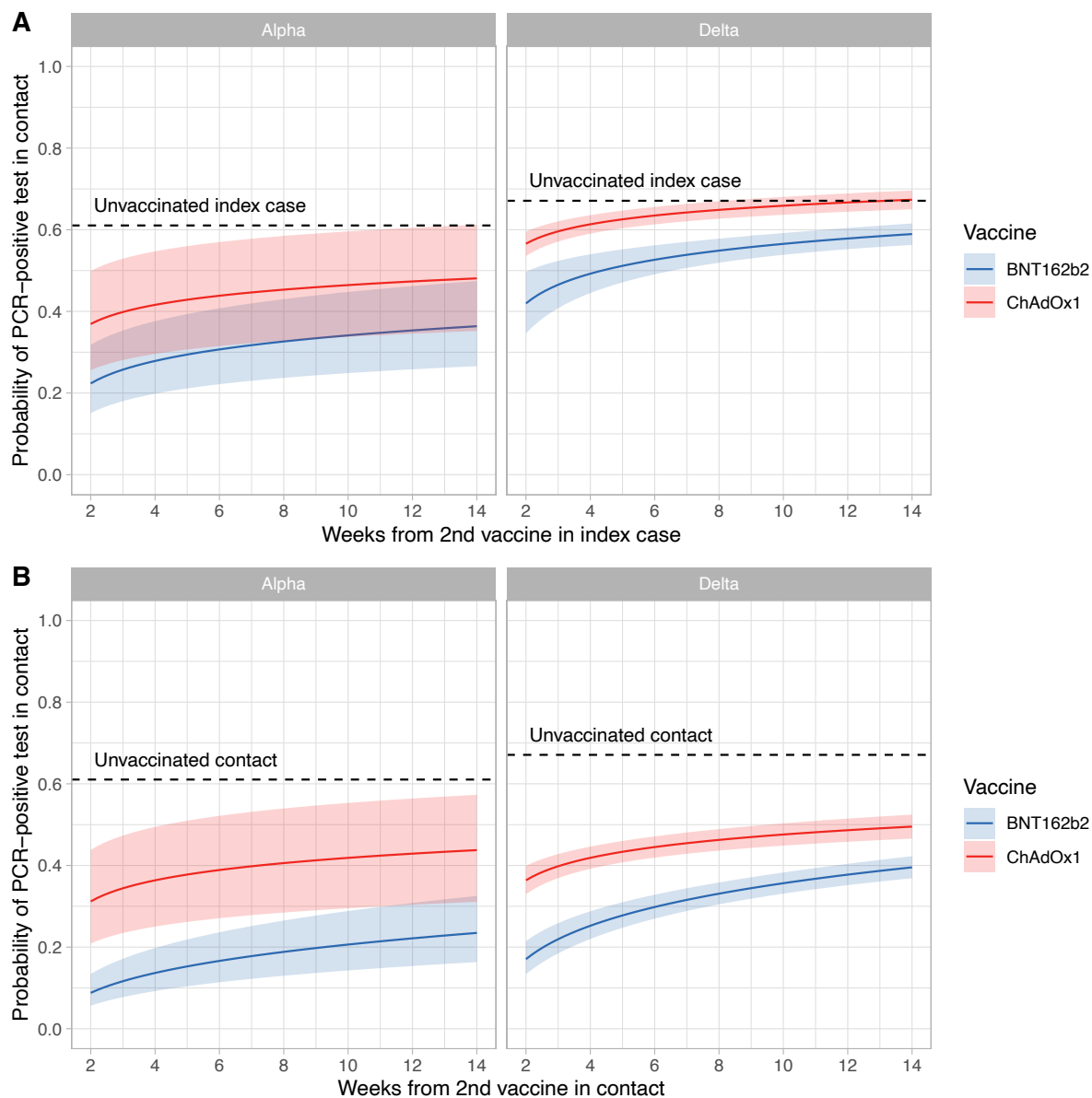
406 **Table 1. Relationship between PCR-positive results in contacts, and index case and contact vaccination status according to Alpha/Delta**

407 **variant in the index case.** Results for those with two vaccine doses are estimated at day 14 post second vaccine, see Figure 3 for trends with

408 time post-second vaccine. aOR, adjusted odds ratio, CI confidence interval. Adjustment made for contact event type; index case factors - age,

409 sex, and symptom status; contact factors - age, sex; local deprivation, local SARS-CoV-2 incidence and calendar time (see Table S4 and Figures  
410 S2-S8 for details).

## 411 Figures



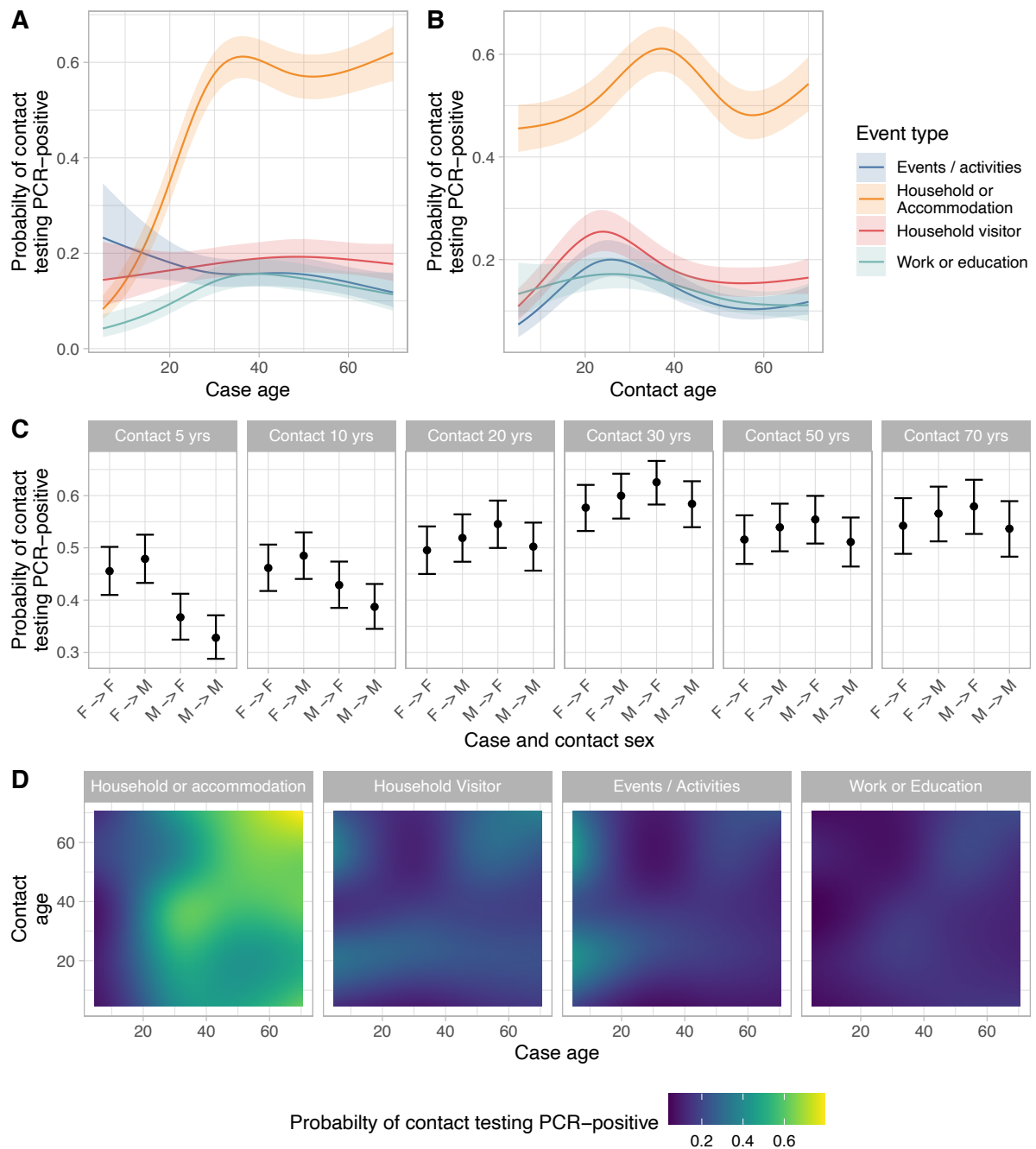
412  
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414 **Figure 1. Estimated probability of a positive PCR test in contacts by time since second**  
415 **vaccination in index cases (panel A) and in contacts (panel B), variant, and vaccine type.**

416 For panel A estimates are displayed for an unvaccinated contact and for panel B for an  
417 unvaccinated index case. The relationships shown also apply to vaccinated contacts and  
418 cases, as the underlying odds ratios are independent of contact and case vaccine status  
419 respectively, however absolute probabilities differ. The dashed horizontal lines indicate the

420 probability of a positive-PCR result in an unvaccinated contact of an unvaccinated index  
421 case. The shaded area indicates the 95% confidence interval. Adjustment made for  
422 covariates, set to reference values: contact event type (set to Household or  
423 accommodation); index case factors – age (median), sex (female), and symptom status  
424 (symptomatic); contact factors – age (median), sex (female); local deprivation (median),  
425 local SARS-CoV-2 incidence (median) and calendar time (median).  
426





427

428

429 **Figure 2. Estimated probability of a positive PCR test in contacts by contact event type and**

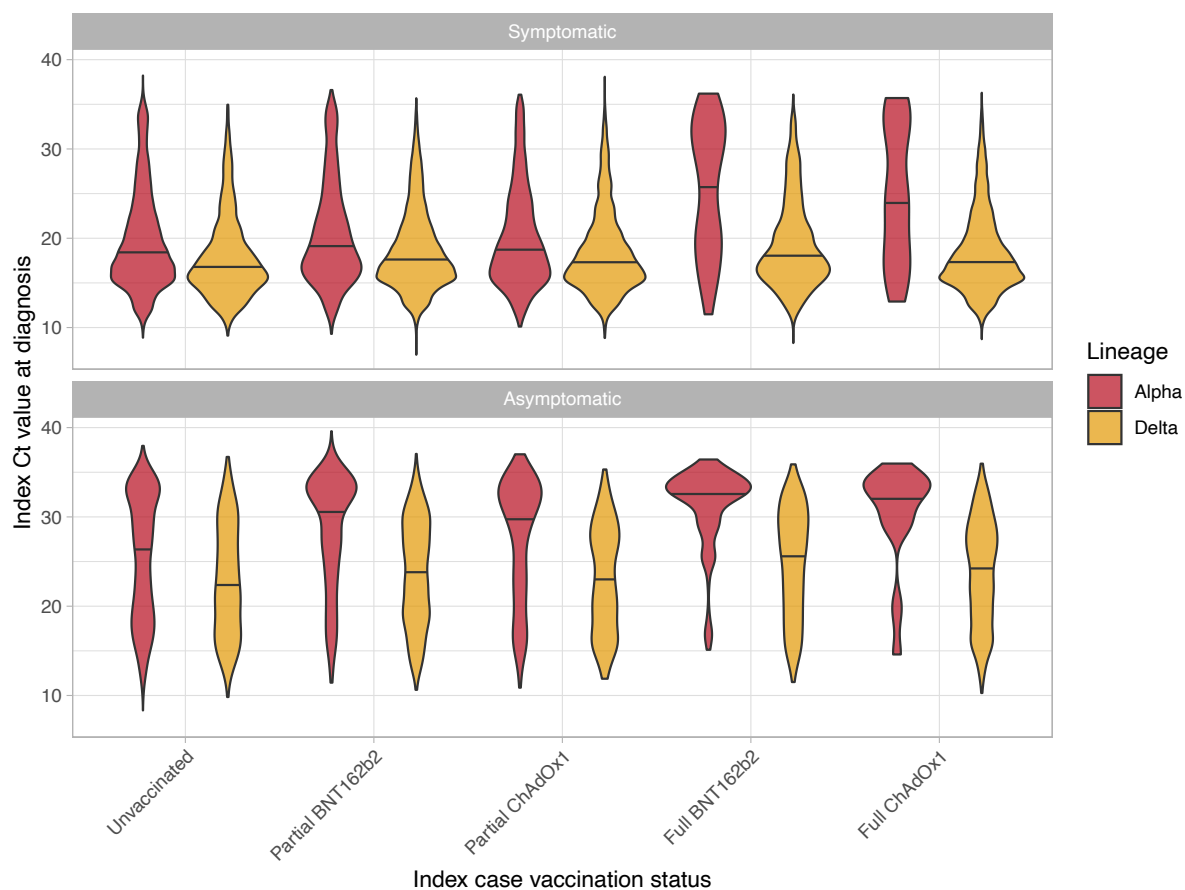
430 **index case age (panel A) or contact age (panel B), contact age and case and contact sex**

431 **(panel C) and case and contact age (panel D). For each panel all other covariates are set to**

432 **reference values for categorical values and median values for continuous variables, i.e.**

433 **contact event type set to Household or accommodation; index case factors – age (median),**

434 sex (female), vaccination status (unvaccinated) and symptom status (symptomatic); contact  
435 factors – age (median), sex (female), vaccination status (unvaccinated); local deprivation  
436 (median), local SARS-CoV-2 incidence (median) and calendar time (median). Shaded ribbons  
437 and error bars indicate 95% confidence intervals.  
438



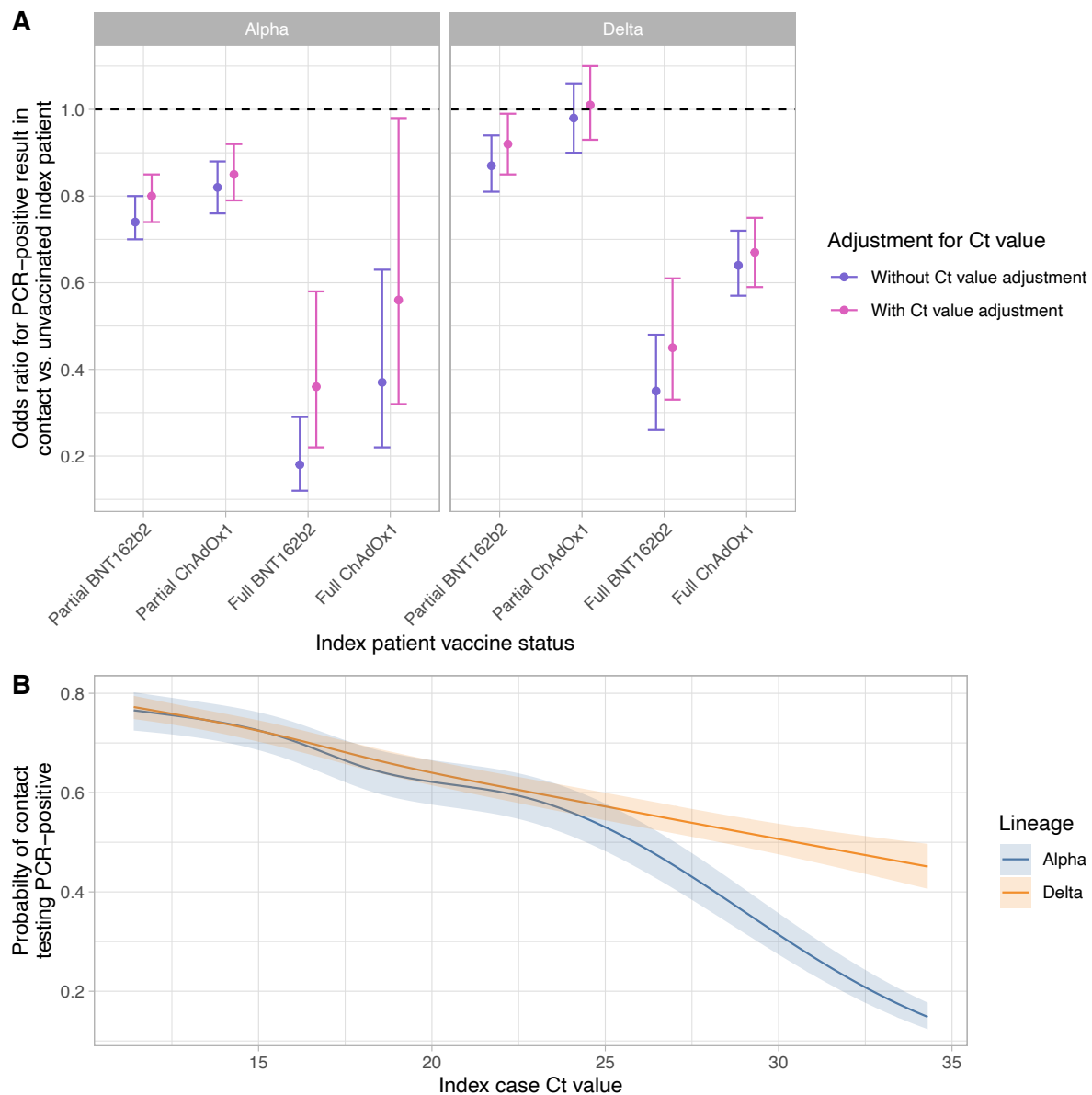
439

440 **Figure 3. Distribution of viral loads by index case vaccination status, variant, and**

441 **symptoms.** The solid line in each violin plot indicates the median. See Lee *et al* for details of

442 equivalent viral loads in copies per ml ( $\log_{10}(\text{VL}) = 12.0 - 0.328 \cdot \text{Ct}$ ).<sup>15</sup>

443



444

445

446 **Figure 4. Extent of vaccine-associated transmission reductions explained by change in**

447 **viral load (Ct values) in index case (panel A) and relationship between Ct values and**

448 **transmission by lineage (panel B). Adjusted odds ratios are shown in panel A and error bars**

449 **(panel A) or the shaded ribbon (panel B) indicate the 95% confidence interval.**