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Predictors of incomplete COVID-19 vaccine schedule among adults in Scotland: Two retrospective cohort analyses of the primary schedule and third dose

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ABSTRACT

Background: Vaccination continues to be the key public health measure for preventing severe COVID-19 outcomes. Certain groups may be at higher risk of incomplete vaccine schedule, which may leave them vulnerable to COVID-19 hospitalisation and death.

Aim: To identify the sociodemographic and clinical predictors for not receiving a scheduled COVID-19 vaccine after previously receiving one.

Methods: We conducted two retrospective cohort studies with ≥3.7 million adults aged ≥18 years in Scotland. Multivariable logistic regression was used to estimate adjusted odds ratios (aOR) of not receiving a second, and separately a third dose between December 2020 and May 2022. Independent variables included sociodemographic and clinical factors.

Results: Of 3,826,797 people in the study population who received one dose, 3,732,596 (97.5%) received two doses, and 3,263,153 (86.5%) received all doses available during the study period.

The most strongly associated predictors for not receiving the second dose were: being aged 18–29 (reference: 50–59 years; aOR:4.26; 95% confidence interval (CI):4.14–4.37); hospitalisation due to a potential vaccine related adverse event of special interest (AESI) (reference: not having a potential AESI, aOR:3.78; 95%CI: 3.29–4.35); and living in the most deprived quintile (reference: least deprived quintile, aOR:3.24; 95%CI: 3.16–3.32).

The most strongly associated predictors for not receiving the third dose were: being 18–29 (reference: 50–59 years aOR:4.44; 95%CI: 4.38–4.49), living in the most deprived quintile (reference: least deprived quintile aOR:2.56; 95%CI: 2.53–2.59), and Black, Caribbean, or African ethnicity (reference: White ethnicity aOR:2.38; 95%CI: 2.30–2.46).

Pregnancy, previous vaccination with mRNA-1273, smoking history, individual and household severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) positivity, and having an unvaccinated adult in the household were also associated with incomplete vaccine schedule.

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Conclusion: We observed several risk factors that predict incomplete COVID-19 vaccination schedule. Vaccination programmes must take immediate action to ensure maximum uptake, particularly for populations vulnerable to severe COVID-19 outcomes.

1. Introduction

The Scottish COVID-19 vaccination programme began on 08 December 2020 and, as of spring 2023, at least three doses of COVID-19 vaccine have been offered to the eligible adult population; two vaccines as part of a primary schedule, and a third to boost the immune response due to potential waning of protection [1]. Immunocompromised individuals were offered a third vaccine as part of their primary dose, with a fourth dose given to further boost protection [2]. Additional booster vaccines have since been offered to some 'at risk groups' in spring/summer 2022 [2], autumn/winter 2022/2023 [3], and in spring 2023 [4].

Although uptake of the first dose of vaccine was initially over 90% in Scotland, uptake of subsequent doses has declined [5]. According to Public Health Scotland, as of 11 September 2022, 91.6% of adults had received one dose of a COVID-19 vaccine, 88.8% had received two, and 78.8% had received either a third dose or first booster [5]. As more COVID-19 booster vaccines are offered, there is concern that vaccine uptake may further decline [6]. Low uptake is relevant given that COVID-19 is still prevalent and vaccines continue to protect against severe COVID-19 outcomes [7,8]. Some of the groups at greatest risk of severe COVID-19 outcomes are also among the most vaccine hesitant. Males, pregnant women, smokers, and persons of Black ethnicity are at higher risk of severe COVID-19 outcomes and have been shown to be more hesitant towards having a COVID-19 vaccine [9–12]. In particular, a study from England showed that Black/African or Caribbean ethnicity, males, and living in high deprivation and urban areas were factors associated with lower uptake of the second dose in those 50 years and older [9].

Previous research has characterised Scottish adults who were unvaccinated against COVID-19 [13]. Here, for the first time, we characterise those who have previously received a vaccine but did not take up the offer of subsequent doses. These individuals are regarded as having an incomplete COVID-19 vaccination schedule and may be at increased risk of severe COVID-19 outcomes. Our aims were to identify the sociodemographic and clinical predictors for not completing the recommended COVID-19 vaccine schedule using the Evaluation and Enhanced Surveillance of COVID-19 (EAVE II) national cohort of individuals in Scotland [14].

2. Methods

2.1. Study design and population

We used data from 4.2 million participants in Scotland who were registered with a GP in March 2020 [14] and received at least one COVID-19 vaccine before 31 May 2022. Two retrospective cohort studies were designed to identify risk-factors for not completing the recommended COVID-19 vaccine schedule among those alive at the study end and who had the chance to get vaccinated with the i) primary schedule, and ii) third dose/first booster COVID-19 vaccination programme. We defined the primary schedule as individuals receiving two vaccines. A third dose was defined as individuals receiving three doses as either the primary schedule or as a booster. We could not differentiate between those who received a third dose as part of their primary schedule or as a booster, therefore they have been combined into a third dose group. Individuals were included in the cohort studies if they were ≥18 years at the time of their first vaccine and were registered with a GP in March 2020.

The primary schedule analysis study period was from 08 December 2020, when the vaccination programme began, to 31 May 2022 (after those eligible to receive a second COVID-19 vaccine had the opportunity to receive it). Individuals were entered into this cohort if they received their first COVID-19 vaccine and were followed up to determine if they received the second dose. The third dose analysis study period began on 14 September 2021 when individuals were first eligible for a third vaccine and ended on 31 May 2022. Individuals were entered into the study if they received a second COVID-19 vaccine and were followed up until 31 May 2022 to determine if they received a third dose.

For both analyses, the outcome was vaccine status at the study end date, among those eligible for vaccination at that time. Individuals were excluded if they died before or during the study period, were vaccinated before the programme began on 08 December 2020, were identified as leaving Scotland/de-registering from their GP practice or had inconsistent vaccine records (for example, a third dose was recorded, but no previous doses). Individuals were also excluded from cohorts one and two, respectively, if they received their first or second vaccine within 16 weeks prior to 31 May 2022, as they may not have had enough follow up time to receive additional doses. For most of the study period, a minimum interval of 12 weeks was recommended between doses [15]. For those who tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) were advised to wait at least four weeks before receiving additional vaccines.

2.2. Data sources

Personal identifiable information was removed from the datasets prior to analyses. Data were deterministically linked using the Community Health Index - a unique patient identifier. Further information on the definitions and caveats of the variables used is provided in Appendix 1.

Health condition information was captured via clinical event coding (Read codes) from GP records and were based on QCOVID risk groups. QCOVID risk groups are health conditions associated with a higher risk of severe COVID-19 outcomes [16]. While causality was not established between these conditions and severe COVID-19 outcomes, they may play a direct role or serve as markers for other risk factors. However, given the increased risk faced by these individuals, regardless of the underlying causal mechanisms, it is crucial to monitor COVID-19 vaccine uptake within these groups. Multimorbidity was defined as those with two or more QCOVID health conditions. Deprivation, health board and urban–rural status were derived from patient postcode. Smoking status was based on GP recorded smoking status, extracted in March 2020. Household identifiers were applied to groups of individuals with the same home address in GP records and used to identify household vaccination and household testing status. A description of how household variables were calculated is provided in Appendix 1. Almost all individuals in Scotland are registered with a GP (estimated >99%), which provide a free service at the point of delivery. Data from all patients registered in general practices in March 2020 were used for this cohort [14,17]. Previous research has indicated a high level of completeness for these Read codes, with an estimated completeness rate of over 91% [18].

Individual-level vaccination records, including vaccination status and vaccine product, were obtained from the National Clinical Data Store (NCDS). Only vaccines that were UK approved during the study period were included: ChAdOx1 nCoV-19, BNT162b2, and mRNA-1273. Age was taken at time of first vaccination and grouped into 18–29, 30–39, 40–49, 50–59, 60–69, 70–79, 80–89, 90+ years. Individual-level records of vaccination are registered in the NCDS for all COVID-19

vaccinations administered in Scotland.

Reverse transcription polymerase chain reaction (RT-PCR) and lateral flow device (LFD) test results were extracted from Electronic Communication of Surveillance in Scotland (ECOSS) and used to identify individuals that had tested positive for SARS-CoV-2. ECOSS collects information on all positive microbiology laboratory specimen results in Scotland.

Hospital admissions with a potential adverse event of special interest (AESI) were identified from the Scottish Morbidity Record 01 (SMR01) inpatient dataset using International Classification of Diseases-10th Revision (ICD-10) [19] coded diagnoses for 36 conditions. Advice from NHS Inform suggested monitoring some side effects for up to 28 days post-vaccination [20]. This was chosen as a period where patients would potentially attribute any new medical conditions requiring hospitalisation to their vaccination. Further information on the AESI selected for this study and their definitions can be found in Appendices 2 and 3.

Ethnicity data were obtained from multiple healthcare data sources, including NCDS, SMR datasets, Rapid Preliminary Inpatient Data, Unscheduled Care, and ECOSS. Data were only extracted from vaccination records if ethnicity was available from another data source (described further in Appendix 1).

Pregnant women were identified from the COVID-19 in Pregnancy in Scotland (COPS) cohort [21] which used multiple data sources including antenatal booking, general and maternity hospital discharge, GP, statutory termination of pregnancy records, and statutory live and stillbirth registrations. The pregnancy registry used to identify pregnant women in Scotland is near complete with only those who did not seek medical advice during their pregnancy not included [21]. We identified women who had become pregnant since their previous vaccine, where estimated date of conception was after the date of prior vaccination. An individual was defined as being pregnant using the estimated date of conception (2 + 0 gestation) until the pregnancy end. Pregnancy status was determined at first dose, and 16 weeks after the first dose for the analysis of the primary schedule (when they were eligible for the second dose) and the start of the third dose programme (15 September 2021) for the analysis of the third dose. Women who became pregnant after these time points would not be identified as pregnant.

2.3. Data analyses

Crude and age-sex adjusted uptake rates for each outcome were calculated for each covariate of interest. Multivariable logistic regression models were used to calculate the adjusted odds ratio (aOR) of not receiving a second and third vaccine dose, with a binary outcome for vaccine status denoting whether individuals had received the vaccination of interest by 31 May 2022. The models included sex, age, ethnicity, deprivation, previous vaccine product, household vaccination status, household testing status, smoking status, positive COVID-19 test after previous vaccination, hospitalisation for a potential AESI, health board, and urban–rural status. In addition, the impact of multimorbidity, and health conditions were explored in separate models to prevent issues with collinearity.

Sub-analyses were conducted to characterise incomplete vaccine schedule in pregnancy. Analyses were restricted to women aged 18–55 years at the time of their first COVID-19 vaccine. Women were only entered into the cohort if they received their first vaccine dose after 16 April 2021. Prior to this date, only pregnant women in a high clinical risk group or pregnant health and care workers at high occupational exposure risk were offered vaccination during pregnancy. After this date, all pregnant women were offered their first COVID-19 vaccine at the same time as non-pregnant women, based on their age and clinical risk group [11].

All statistical analyses were conducted using R version 3.6.1 [22].

3. Results

3.1. Study exclusions and missing data

Of the 4.2 million people in the EAVE-II cohort who had received at least one COVID-19 vaccine before 31 May 2022, 76,980 died before or during the study and 23,255 did not reside in Scotland during the study period and were therefore excluded from the analysis. In addition, 9,812 were excluded due to inconsistent vaccine records and 306,445 were under 18 years at the time of their first vaccine. A further 7,718 were excluded because they received their first dose within 16 weeks of the study end date (Figure 1). 97,066 individuals did not receive a second COVID-19 vaccine prior to 8 February 2022 (16 weeks before 31 May 2022) and therefore were not entered into the second cohort. A further 25,699 were excluded because they received their second dose within 16 weeks of the end of the study period (Figure 1).

The data demonstrated minimal missingness (Table 1), with less than 1% of deprivation quintile and household vaccination status covariates missing. However, there were instances of missing ethnicity information, with 26.8% of records missing from the primary schedule cohort and 26.9% from the third dose cohort. Smoking status information was missing from 13.5% of records in the primary schedule cohort and 11.9% in the third dose cohort. To minimise any bias associated with using complete cases only, missing data was coded as “unknown”, and all observations retained in the analysis.

3.2. Socio-Demographic and clinical characteristics

Of the 3,826,797 individuals who received the first COVID-19 vaccine, 94,204 (2.5%) did not receive a second dose prior to 31 May 2022, thus not completing their primary schedule (Table 2). Of the 3,711,756 individuals who received a second vaccine, 448,605 (12.1%) did not receive the third dose by 31 May 2022 (Table 3). The age-sex adjusted uptake of those receiving the second and third dose was 97.3%, and 86.5%, respectively.

The lowest age-sex adjusted completion rates of the primary schedule compared to the general population (97.3%) were observed for: those who previously received mRNA-1273 (89.7%), those who experienced a possible AESI within 28 days post previous vaccination (91.72%), persons from a Black, Caribbean, or African ethnicity (94.9%), those with an unvaccinated adult in their household (94.7%), and the highest deprivation quintile (95.1%) (Figure 2 and Table 2). Those with coronary heart disease (CHD) (94.4%), peripheral vascular disease (95.3%), Parkinson’s disease (95.5%), thrombosis or pulmonary embolus (95.8%), severe mental illness (95.9%), and chronic obstructive pulmonary disease (COPD) (96.0%), had a lower age-sex adjusted primary schedule completion rate compared to those without these conditions (Figure 2 and Table 4).

The lowest age-sex adjusted uptake rates of the third dose compared to the general population (86.5%) were observed for: persons from a Black, Caribbean, or African ethnicity (71.5%), those who previously received mRNA-1273 (72.1%), those in the highest deprivation quintile (80.3%), and those with an unvaccinated adult in the household (78.2%) (Figure 2 and Table 3). Those with COPD (83.2%), CHD (84.5%), dementia (84.5%) had a lower age-sex adjusted third dose completion rates compared to those without these conditions (Figure 2 and Table 5).

3.3. Predictors of incomplete vaccine schedule

3.3.1. Primary schedule

The most strongly associated predictors for not receiving the second dose were age, having a potential AESI and socioeconomic status. Those aged 18–29 years were over four times as likely to not receive a second vaccine dose (reference: 50–59 years aOR: 4.26; 95% confidence interval: 4.14–4.37). Those who were hospitalised due to a possible AESI within 28 days of vaccination were over 3.5 times more likely to not

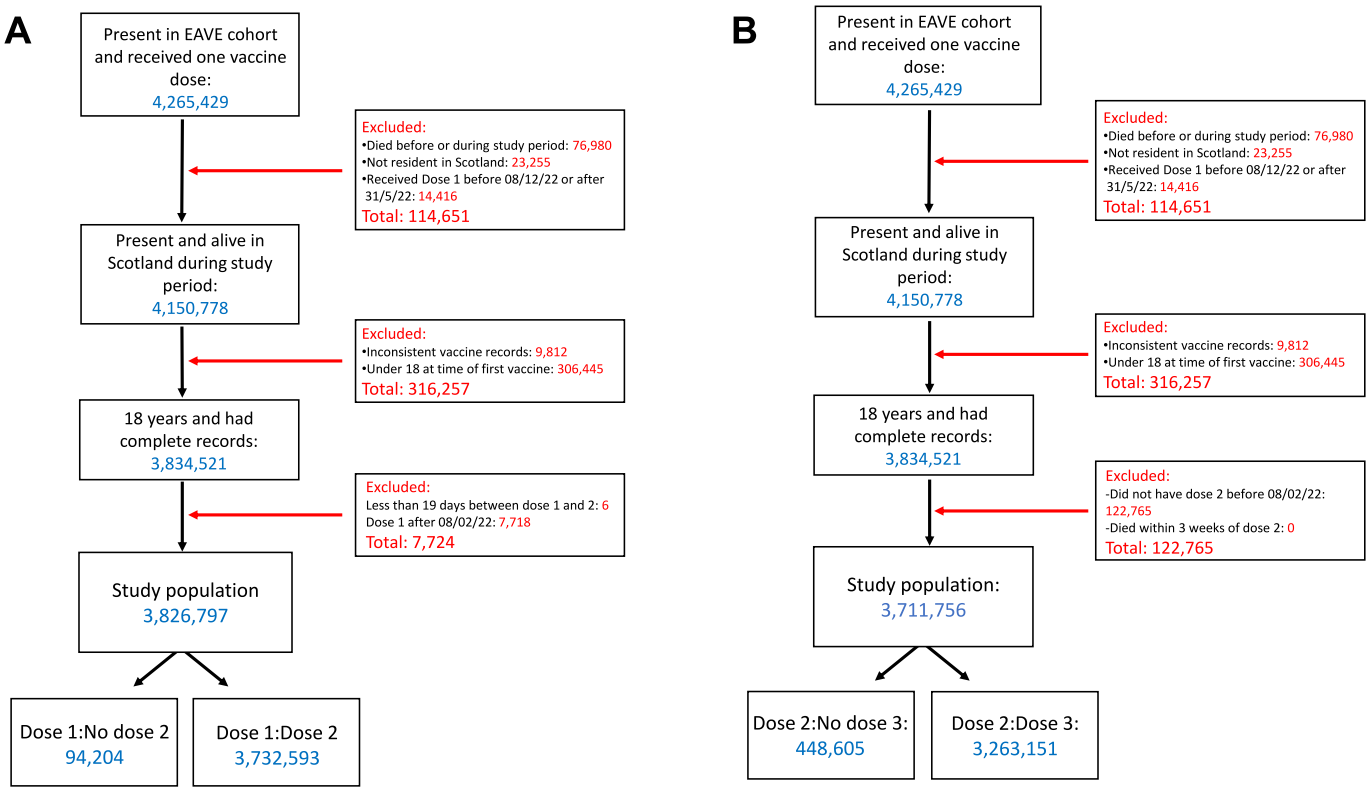

Fig. 1. Flow diagram of exclusions from A) primary schedule analysis, B) third dose analysis.

Table 1
Missing data summary of study cohorts.

Variable	Number Missing (%)	
	Primary Schedule Cohort	Third Dose Cohort
Sex	0 (0%)	0 (0%)
Age	0 (0%)	0 (0%)
Ethnicity	998,291 (26.75%)	879,188 (26.94%)
Deprivation Quintile	22,645 (0.61%)	18,696 (0.57%)
Previous Vaccine Product	0 (0%)	0 (0%)
Household Vaccination Status (over 18 years)	1,895 (0.05%)	1,181 (0.03%)
Number of Q Covid Risk Groups	0 (0%)	0 (0%)
Smoking Status	505,052 (13.53%)	389,035 (11.92%)
Hospitalisation due to a Potential Adverse Event within 28 Days	0 (0%)	0 (0%)
Tested Positive After Vaccination	0 (0%)	0 (0%)
Household Positive Test before next Vaccine	0 (0%)	0 (0%)

receive a second vaccine dose (reference: no AESI aOR:3.78; 95% CI: 3.29–4.35). Those living in the most deprived quintile were over three times more likely to not receive a second vaccine dose (reference: least deprived quintile aOR:3.24; 95% CI:3.16–3.32), and those who smoke were 2.5 times more likely to not receive a second vaccine dose (reference: non-smokers aOR: 2.48; 95% CI: 2.43–2.52) (Figure 3 and Table 2).

We also observed that being from a Black, Caribbean, or African ethnic background (reference: White ethnicity aOR:1.37; 95% CI: 1.28–1.45), receiving mRNA-1273 as the previous vaccine (reference: BNT162b2 aOR: 1.48; 95% CI:1.45–1.51), living with an unvaccinated adult in the household in comparison to (reference: vaccinated adult in the household aOR: 2.35; 95% CI: 2.31–2.39) and having someone in the household who tested positive for SARS-CoV-2 (reference: no household SARS-CoV-2 positive test aOR:1.98; 95% CI: 1.92–2.03) were also risk-factors for not completing the primary schedule (Figure 3 and Table 2).

Those with thrombosis or pulmonary embolus (aOR: 1.43; 95% CI: 1.32–1.56), severe mental illness (aOR: 1.39; 95%CI:1.28–1.52), cirrhosis of the liver (aOR:1.22; 95%CI:1.04–1.44), epilepsy (aOR: 1.21; 95% CI:1.15–1.27), prior fracture of hip, wrist, spine or humerus (fragility fracture) (aOR: 1.10; 95% CI: 1.07–1.14), history of stroke (aOR:1.11; 95% CI:1.03–1.19), chronic obstructive pulmonary disease (COPD) (aOR:1.08; 95% CI:1.02–1.14) and learning disabilities (aOR:1.06; 95% CI:1.01–1.12) were more likely to not receive the second dose compared to those without these health conditions (Figure 3 and Table 4).

Women aged 18–55 years who were not pregnant at their first dose but were pregnant at 16 weeks after their first dose, were over two times more likely to not receive the second dose (reference: women who were not pregnant 16 weeks after their first dose aOR: 2.42; 95% CI:2.25–2.59) (Figure 3 and Table 6).

3.3.2. *Third dose schedule*

The most strongly associated predictors for not receiving the third dose were being 18–29 years (reference: 50–59 years aOR:4.44; 95% CI:4.38–4.49), living in the most deprived quintile (reference: least deprived quintile aOR:2.56; 95%CI:2.53–2.59), being from a Black, Caribbean, or African ethnic background (reference: White ethnicity aOR:2.38; 95% CI:2.30–2.46), and having an unvaccinated adult in the household (reference: adults with at least one vaccine within the household aOR:2.08; 95% CI:2.06–2.10) (Figure 3 and Table 3).

Asian or Asian British ethnic groups had lower aOR of not completing the primary schedule (reference: White ethnicity aOR:0.94; 95% CI:0.90–0.98) (Table 2), however they had higher aOR of not receiving the third dose (aOR:1.39; 95%CI:1.37–1.42) (Figure 3 and Table 3). Smokers were over 90% less likely to receive the third dose compared to non-smokers (aOR 1.91; 95%CI: 1.89–1.93); those who had a possible

Table 2
Number and proportion of individuals aged 18 years and above who received a second dose of COVID-19 vaccine between 08 December 2020 and 31 May 2022 in Scotland and the odds of not receiving a second dose of COVID-19 vaccine by sociodemographic covariates.

Variable	Vaccinated with dose one who were vaccinated with dose two		Age-sex adjusted rates		Odds of not receiving dose two			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Total	3,732,593	97.54	97.28	97.28—97.28	–	–	–	–
Sex								
Female	1,956,241	97.89	97.65[1]	97.65—97.65[1]	Reference			
Male	1,776,355	97.16[1]	96.91[1]	96.91—96.91[1]	1.36	1.34–1.38	1.23	1.21–1.24
Age								
18–29	545,082	93.72	93.70[2]	93.70—93.70[2]	4.85	4.74–4.96	4.26	4.14–4.37
30–39	543,735	95.40	95.38[2]	95.38—95.38[2]	3.53	3.45–3.62	3.17	3.09–3.26
40–49	562,339	97.23	97.22[2]	97.22—97.22[2]	2.09	2.04–2.15	2.12	2.06–2.18
50–59	716,322	98.66	98.66[2]	98.66—98.66[2]	Reference			
60–69	638,257	99.39	99.39[2]	99.39—99.39[2]	0.45	0.44–0.47	0.45	0.44–0.47
70–79	471,256	99.72	99.72[2]	99.72—99.72[2]	0.21	0.20–0.22	0.21	0.20–0.23
80–89	214,648	99.78	99.79[2]	99.79—99.79[2]	0.17	0.15–0.18	0.19	0.17–0.21
90+	40,957	99.74	99.77[2]	99.77—99.77[2]	0.19	0.15–0.23	0.24	0.19–0.29
Ethnicity								
White	2,601,256	97.51	97.14	97.14—97.14	Reference			
Asian or Asian British	83,207	96.62	97.22	97.22—97.22	1.34	1.29–1.39	0.94	0.90–0.98
Black, Caribbean, or African	17,919	93.87	94.92	94.91—94.93	2.48	2.33–2.64	1.37	1.28–1.45
Mixed or Multiple	16,174	95.47	96.9	96.89—96.91	1.82	1.69–1.95	1.06	0.98–1.14
Other	15,749	95.06	95.84	95.83—95.85	2.03	1.89–2.17	1.17	1.09–1.26
Unknown	998,291	97.83	97.71	97.71—97.71	0.87	0.85–0.89	0.92	0.90–0.93
Deprivation Quintile								
1 – High	678,383	95.25	95.13	95.13—95.13	4.37	4.27–4.47	3.24	3.16–3.32
2	724,258	96.93	96.68	96.68—96.68	2.76	2.69–2.82	2.31	2.25–2.37
3	748,416	97.96	97.67	97.67—97.67	1.82	1.77–1.87	1.71	1.67–1.76
4	783,494	98.49	98.26	98.26—98.26	1.34	1.30–1.38	1.32	1.29–1.36
5-Low	775,400	98.86	98.7	98.7—98.7	Reference			
Unknown	22,645	95.80	96.33	96.32—96.34	3.84	3.59–4.11	2.53	2.35–2.73
Previous Vaccine Product								
BNT162b2	1,615,566	96.72	97.31	97.31—97.31	Reference			
ChAdOx1 nCoV-19	1,952,446	98.66	98.1	98.1—98.1	0.41	0.40–0.41	0.80	0.79–0.82
mRNA-1273	164,584	92.74	89.72	89.72—89.72	2.31	2.26–2.35	1.48	1.45–1.51
Household Vaccination Status (over 18 years)								
No Unvaccinated in Household	2,248,307	97.98	97.91	97.91—97.91	Reference			
Unvaccinated in Household	347,898	94.43	94.72	94.72—94.72	2.88	2.83–2.93	2.35	2.31–2.39
Unknown	1,895	89.81	96.95	96.85—97.05	5.37	4.64–6.20	1.91	1.65–2.21
Lives Alone	1,120,596	97.66	96.86	96.86—96.86	1.17	1.16–1.19	1.51	1.48–1.53
Care home/Other	13,900	98.39	95.71	95.7—95.72	0.81	0.71–0.93	1.48	1.29–1.69
Number of Q Covid risk groups								
0	1,993,932	96.93	97.26	97.26—97.26	Reference			
1	1,117,191	97.89	97.36	97.36—97.36	0.69	0.68–0.70	0.96	0.95–0.98
2	401,737	98.70	97.41	97.41—97.41	0.42	0.41–0.43	0.92	0.89–0.94
3/4	193,962	99.24	97.3	97.3—97.3	0.24	0.23–0.26	0.91	0.86–0.96
5+	25,774	99.59	97.24	97.23—97.25	0.13	0.11–0.16	0.76	0.63–0.92
Smoking Status								
Never	1,764,267	98.37	98.27	98.27—98.27	Reference			
Ex-Smoker	576,018	98.83	97.45	97.45—97.45	0.72	0.71–0.74	1.33	1.29–1.37
Smoker	887,259	96.65	95.11	95.11—95.11	2.11	2.07–2.14	2.48	2.43–2.52
Unknown	505,052	95.86	96.43	96.43—96.43	3.25	3.19–3.30	1.85	1.82–1.88
Hospitalisation due to a Potential Adverse Event within 28 Days								
No	3,727,432	97.54	97.29	97.29—97.29	Reference			
Yes	5,164	95.67	91.72	91.69—91.75	1.62	1.47–1.78	3.78	3.29–4.35
Tested Positive After Vaccination								
No	2,686,088	97.58	97.03	97.03—97.03	Reference			
0–2 weeks	18,525	93.77	95.37	95.36—95.38	2.65	2.49–2.81	1.32	1.25–1.41
3–4 weeks	8,981	91.61	94.03	94.01—94.05	3.67	3.42–3.95	1.95	1.81–2.10
5–8 weeks	25,578	90.00	92.75	92.74—92.76	4.42	4.25–4.60	2.12	2.03–2.21
9–16 weeks	42,562	89.50	92.62	92.62—92.62	4.68	4.54–4.83	2.67	2.58–2.75
Over 16 weeks	950,862	98.16	92.62	92.62—92.62	0.76	0.75–0.77	0.60	0.59–0.61
Household Positive Test before next Vaccine								
No	2,520,429	97.66	97.57	97.57—97.57	Reference			
Yes	77,671	92.27	94.92	94.92—94.92	3.39	3.30–3.48	1.98	1.92–2.03

N= Number, AR = Adjusted rate, 95% CI = 95% confidence interval, UOR = Unadjusted odds ratio, AOR = Adjusted odds ratio, [1] = age adjusted rate, [2] = sex adjusted rate.

AESI within 28 days of vaccination were 80% less likely to receive the third dose compared to those who did not (aOR: 1.80; 95% CI:1.62–1.99), and those who had someone in their household test positive for SARS-CoV-2 were over 70% less likely to receive the third dose compared to individuals who did not (aOR 1.73; 95%CI: 1.71–1.75). Being male in comparison to female (aOR:1.29; 95% CI:1.28–1.30) and receiving mRNA-1273 as the previous vaccine product compared to BNT162b2 (aOR:1.33; 95%CI1.31–1.34) were also predictors for not receiving a third vaccine dose.

Individuals with COPD (aOR:1.11; 95%CI:1.08–1.14), history of stroke (aOR:1.07; 95%CI:1.04–1.11), and prior fracture of hip, wrist, spine or humerus (fragility fracture) (aOR:1.06; 95%CI:1.04–1.08) were

Table 3
Number and proportion of individuals aged 18 years and above who received a third dose of COVID-19 vaccine between 08 December 2020 and 31 May 2022 in Scotland and the odds of not receiving a third dose of COVID-19 vaccine by sociodemographic covariates.

Variable	Vaccinated with dose two who were vaccinated with dose three		Age-sex adjusted rates		Odds of not receiving third dose			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Total	3,263,151	87.91	86.46	86.46—86.46	–		–	
Sex								
Female	1,737,224	89.28	87.96[1]	87.96—87.96[1]	Reference			
Male	1,525,929	86.41	84.97[1]	84.97—84.97[1]	1.31	1.31–1.32	1.29	1.28–1.30
Age								
18–29	382,662	71.66	71.54[2]	71.54—71.54[2]	4.58	4.53–4.63	4.44	4.38–4.49
30–39	414,520	77.03	76.92[2]	76.92—76.92[2]	3.53	3.49–3.56	3.41	3.37–3.45
40–49	479,048	85.55	85.48[2]	85.48—85.48[2]	2.00	1.98–2.02	2.01	1.99–2.04
50–59	659,934	92.27	92.24[2]	92.24—92.24[2]	Reference			
60–69	613,167	96.14	96.13[2]	96.13—96.13[2]	0.48	0.47–0.49	0.50	0.49–0.51
70–79	462,311	98.14	98.14[2]	98.14—98.14[2]	0.23	0.22–0.23	0.26	0.25–0.26
80–89	211,236	98.51	98.48[2]	98.48—98.48[2]	0.18	0.18–0.19	0.23	0.22–0.24
90+	40,275	98.45	98.49[2]	98.49—98.49[2]	0.19	0.18–0.21	0.26	0.24–0.28
Ethnicity								
White	228,4047	88.30	86.37	86.37—86.37	Reference			
Asian or Asian British	64,761	78.840	81.83	81.83—81.83	2.04	2.00–2.07	1.39	1.37–1.42
Black, Caribbean, or African	11,480	65.58	71.48	71.47—71.49	4.02	3.89–4.15	2.38	2.30–2.46
Mixed or Multiple	12,327	77.13	83	82.99—83.01	2.24	2.16–2.32	1.25	1.20–1.30
Other	11,350	73.04	77.09	77.08—77.1	2.80	2.70–2.90	1.76	1.69–1.83
Unknown	879,188	88.47	87.63	87.63—87.63	0.99	0.98–0.99	0.97	0.97–0.98
Deprivation Quintile								
1 – High	546,135	81.22	80.27	80.27—80.27	2.91	2.88–2.94	2.56	2.53–2.59
2	616,657	85.71	84.25	84.25—84.25	2.08	2.06–2.10	1.96	1.94–1.98
3	661,492	88.81	87.04	87.04—87.04	1.57	1.55–1.59	1.58	1.57–1.60
4	706,249	90.54	89.05	89.05—89.05	1.29	1.28–1.31	1.31	1.30–1.33
5-Low	713,924	92.42	91.27	91.27—91.27	Reference			
Unknown	18,696	83.23	84.38	84.37—84.39	2.52	2.43–2.61	1.90	1.82–1.98
Previous Vaccine Product								
BNT162b2	1,357,337	84.41	86.66	86.66—86.66	Reference			
ChAdOx1 nCoV-19	1,795,007	92.23	88.56	88.56—88.56	0.46	0.46–0.47	0.92	0.91–0.93
mRNA-1273	110,809	70.35	72.07	72.07—72.07	2.29	2.26–2.31	1.33	1.31–1.34
Household Vaccination Status (over 18 years)								
No Unvaccinated in Household	1,938,075	89.93	88.32	88.32—88.32	Reference			
Unvaccinated in Household	311,336	77.63	78.2	78.2—78.2	2.36	2.33–2.38	2.08	2.06–2.10
Unknown	1,181	65.98	85.31	85.17—85.45	3.91	3.53–4.33	1.54	1.39–1.71
Lives Alone	999,552	89.58	86.1	86.1—86.1	0.95	0.94–0.95	1.26	1.25–1.27
Care home/Other	13,009	94.05	83.36	83.35—83.37	0.52	0.48–0.55	1.11	1.03–1.20
Number of Q Covid risk groups								
0	1,679,618	84.88	85.31	85.17—85.45	Reference			
1	996,362	89.56	87.05	87.05—87.05	0.66	0.65–0.66	0.89	0.89–0.90
2	375,556	93.67	87.96	87.96—87.96	0.38	0.38–0.39	0.79	0.78–0.81
3/4	186,572	96.28	89.17	89.17—89.17	0.22	0.21–0.23	0.77	0.75–0.79
5+	25,045	97.25	93.03	93.02—93.04	0.16	0.15–0.17	0.82	0.76–0.89
Smoking Status								
Never	1,579,133	89.92	89.18	89.18—89.18	Reference			
Ex-Smoker	534,851	93.07	86.43	86.43—86.43	0.67	0.66–0.68	1.22	1.20–1.23
Smoker	760,134	86.06	80.68	80.68—80.68	1.47	1.46–1.48	1.91	1.89–1.93
Unknown	389,035	78.18	84.04	84.04—84.04	2.48	2.45–2.50	1.49	1.48–1.50
Hospitalisation Due to a **Potential Adverse Event within 28 Days**								
No	3,258,251	87.90	86.47	86.47—86.47	Reference			
Yes	4,902	91.27	82.31	82.28—82.34	0.63	0.59–0.68	1.80	1.62–1.99
Tested Positive After Vaccination								
No	2,416,201	88.76	86.31	86.31—86.31	Reference			
0–2 weeks	10,074	74.36	80.87	80.85—80.89	2.68	2.57–2.78	1.36	1.30–1.42
3–4 weeks	6,059	74.21	79.72	79.69—79.75	2.70	2.57–2.84	1.76	1.67–1.86
5–8 weeks	17,998	74.59	79.99	79.98—80	2.64	2.57–2.72	1.76	1.70–1.81
9–16 weeks	69,875	76.08	81.83	81.83—81.83	2.43	2.39–2.47	1.60	1.57–1.63
Over 16 weeks	742,946	87.20	81.83	81.83—81.83	1.15	1.14–1.16	0.93	0.92–0.93
Household Positive Test before next Vaccine								
No	2,164,395	88.30	87.18	87.18—87.18	Reference			
Yes	86,197	71.24	80.13	80.13—80.13	2.89	2.85–2.93	1.73	1.71–1.75

N= Number, AR = Adjusted rate, 95% CI = 95% confidence interval, UOR = Unadjusted odds ratio, AOR = Adjusted odds ratio, [1] = age adjusted rate, [2] = sex adjusted rate.

11%, 7% and 6% more likely to not receive a third dose compared to those without these conditions, respectively (Figure 3 and Table 5).

Those who were not pregnant at their second dose but pregnant when the third dose programme began on 15 September 2021 were over twice as likely (aOR: 2.03; 95%CI: 1.94–2.13) to not receive the third dose compared to those who were not pregnant when the third dose programme began (Figure 3 and Table 6).

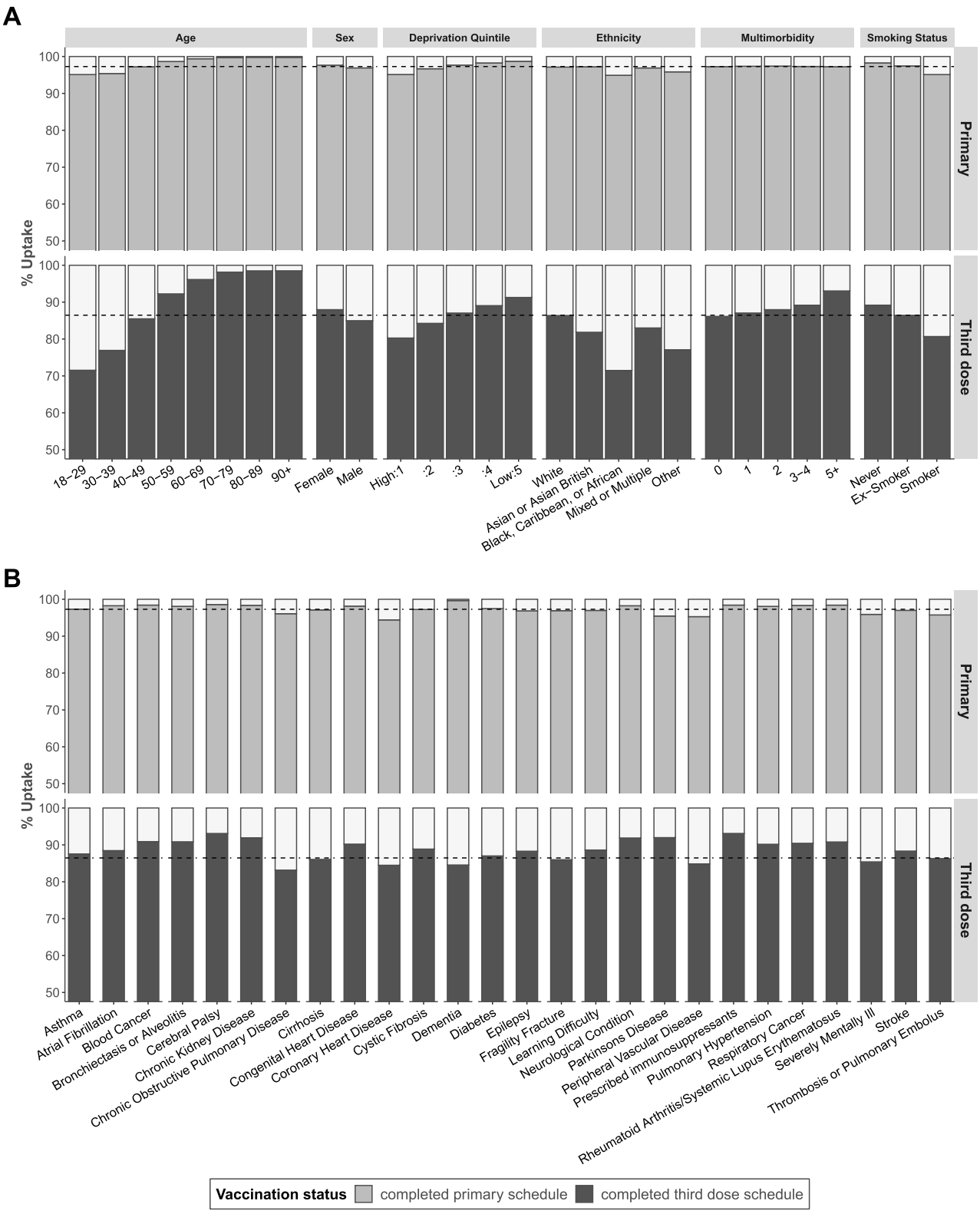

Fig. 2. Standardised uptake for the primary and third dose COVID-19 vaccination programme by (A) sociodemographic and (B) clinical factors for the EAVE II cohort of 3.7 million people in Scotland. Horizontal dotted lines represent age-sex standardised uptake of general adult population. For both plots the x-axes cross the y-axes at 50%. Age is sex standardised, sex is age standardised, all other variables are age-sex standardised.

4. Discussion

These national analyses of over 3.7 million vaccinated adults in Scotland found several common risk-factors associated with disengaging from the COVID-19 vaccination programmes including younger age, higher deprivation, ethnic minority background, and smoking history. Whilst many of these factors have previously been associated with COVID-19 vaccine hesitancy, non-vaccination, and under-vaccination

Table 4
Number and proportion of individuals aged 18 years and above who received a second COVID-19 vaccine between 08 December 2020 and 31 May 2022 in Scotland and the odds of not receiving a second dose COVID-19 vaccine by QCOVID risk group.

Variable	Vaccinated with dose one who were vaccinated with dose two		Age-sex adjusted rates		Odds of not receiving dose two			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Learning Disabilities								
No	3,688,480	97.55	97.28	97.28—97.28	Reference			
Yes	42,626	96.16	96.97	96.97—96.97	1.60	1.52–1.68	1.06	1.01–1.12
Chronic Kidney Disease								
No/Level 1–2	3,578,035	97.45	97.28	97.28—97.28	Reference			
Yes	154,539	99.63	98.36	98.36—98.36	0.14	0.13–0.16	0.81	0.74–0.88
Atrial Fibrillation								
No	3,627,511	97.48	97.28	97.28—97.28	Reference			
Yes	105,085	99.62	98.25	98.25—98.25	0.15	0.14–0.16	0.80	0.72–0.89
Asthma								
No	3,298,478	97.57	97.28	97.28—97.28	Reference			
Yes	434,118	97.32	97.32	97.32—97.32	1.11	1.08–1.13	1.02	1.00–1.05
Blood Cancer								
No	3,714,183	97.53	97.28	97.28—97.28	Reference			
Yes	18,413	99.26	98.42	98.41—98.43	0.30	0.25–0.35	0.71	0.60–0.84
Cystic Fibrosis								
No	3,690,579	97.52	97.28	97.28—97.28	Reference			
Yes	42,017	99.40	97.23	97.23—97.23	0.24	0.21–0.27	0.99	0.87–1.13
Cerebral Palsy								
No	3,727,432	97.54	97.28	97.28—97.28	Reference			
Yes	5164	98.40	98.57	98.53—98.61	0.66	0.53–0.81	0.52	0.42–0.65
Coronary Heart Disease								
No	3,555,373	97.45	97.29	97.29—97.29	Reference			
Yes	177,223	99.35	94.4	94.4—94.4	0.25	0.24–0.27	0.93	0.87–0.99
Cirrhosis								
No	3,722,957	97.54	97.28	97.28—97.28	Reference			
Yes	9,639	98.46	97.11	97.09—97.13	0.63	0.54–0.74	1.22	1.04–1.44
Congenital Heart Disease								
No	3,715,143	97.54	97.28	97.28—97.28	Reference			
Yes	17,453	97.97	98.14	98.13—98.15	0.83	0.75–0.92	0.82	0.74–0.91
Chronic Obstructive Pulmonary Disease								
No	3,624,802	97.51	97.3	97.3—97.3	Reference			
Yes	107,794	98.78	96.08	96.08—96.08	0.49	0.46–0.52	1.08	1.02–1.14
Dementia								
No	3,713,099	97.53	97.28	97.28—97.28	Reference			
Yes	19,497	99.65	99.64	99.63—99.65	0.14	0.11–0.18	0.99	0.78–1.27
Diabetes								
No	2,685,825	97.12	97.25	97.25—97.25	Reference			
Yes	1,046,771	98.63	97.48	97.48—97.48	0.47	0.46–0.48	0.86	0.84–0.88
Epilepsy								
No	3,675,297	97.59	97.29	97.29—97.29	Reference			
Yes	57,299	97.21	96.86	96.86—96.86	1.16	1.10–1.21	1.21	1.15–1.27
Prior Fracture of Hip, Wrist, Spine Or Humerus (Fragility Fracture)								
No	3,550,843	97.52	97.3	97.3—97.3	Reference			
Yes	181,753	97.85	96.91	96.91—96.91	0.87	0.84–0.90	1.10	1.07–1.14
Prescribed immunosuppressants								
No	3,731,072	97.54	97.28	97.28—97.28	Reference			
Yes	1,524	98.58	98.42	98.29—98.55	0.56	0.36–0.86	0.69	0.45–1.06
Neurological Condition								
No	3,715,180	97.53	97.28	97.28—97.28	Reference			
Yes	17,416	99.00	98.24	98.23—98.25	0.40	0.34–0.46	0.66	0.57–0.77
Parkinson's Disease								
No	3,723,793	97.54	97.28	97.28—97.28	Reference			
Yes	8,803	99.66	95.45	95.43—95.47	0.14	0.10–0.20	0.77	0.53–1.11
Pulmonary Hypertension								
No	3,726,490	97.54	97.28	97.28—97.28	Reference			
Yes	6,106	99.58	98.08	98.05—98.11	0.17	0.11–0.24	0.63	0.43–0.93
Bronchiectasis or Alveolitis								
No	3,710,687	97.53	97.28	97.28—97.28	Reference			
Yes	21,909	99.24	98.09	98.08—98.1	0.30	0.26–0.35	0.98	0.84–1.15
Peripheral Vascular Disease								
No	3,721,900	97.53	97.28	97.28—97.28	Reference			
Yes	10,696	99.10	95.29	95.27—95.31	0.37	0.30–0.45	1.00	0.82–1.22
Stroke								
No	3,626,399	97.49	97.29	97.29—97.29	Reference			
Yes	106,197	99.24	96.99	96.99—96.99	0.30	0.28–0.32	1.11	1.03–1.19
Thrombosis or Pulmonary Embolus								
No	3,695,023	97.53	97.29	97.29—97.29	Reference			
Yes	37,573	98.42	95.75	95.75—95.75	0.64	0.59–0.70	1.43	1.32–1.56
Rheumatoid Arthritis or Systemic Lupus Erythematosus								
No	3,650,970	97.55	97.27	97.27—97.27	Reference			

(*continued on next page*)

Table 4 (*continued*)

Variable	Vaccinated with dose one who were vaccinated with dose two		Age-sex adjusted rates		Odds of not receiving dose two			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Yes	81,626	99.00	98.41	98.41—98.41	0.40	0.37–0.43	0.73	0.68–0.78
Respiratory Cancer								
No	3,727,836	97.54	97.28	97.28—97.28	Reference			
Yes	4,760	99.33	98.33	98.29—98.37	0.27	0.19–0.38	0.73	0.51–1.04
Severely Mentally Ill								
No	3,716,246	97.55	97.29	97.29—97.29	Reference			
Yes	16,350	96.63	95.9	95.89—95.91	1.40	1.28–1.52	1.39	1.28–1.52

N= Number, AR = Adjusted rate, 95% CI = 95% confidence interval, UOR = Unadjusted odds ratio, AOR = Adjusted odds ratio.

[13,23–25], we have for the first time shown that individuals were more likely to disengage from the COVID-19 vaccination programme if they were hospitalised with a potential AESI, became pregnant since their previous dose, and had an unvaccinated adult in their household or a household member positive for SARS-CoV-2 post vaccination. Having conditions including cirrhosis of the liver, COPD, and epilepsy also increased the aOR for not completing the recommended COVID-19 vaccine schedules.

Evidence suggests that SARS-CoV-2 infection during pregnancy increased the risk of severe outcomes for mother and baby [26,27]. The COVID-19 vaccines are safe to receive in pregnancy [28–30] and can reduce the risk of severe outcomes if infected with SARS-CoV-2. Despite this evidence there is significant vaccine hesitancy in this group [31]. In Scotland, vaccine uptake in pregnant women has been lower than in the general female population [32]. Here, we observed that those who became pregnant after previously accepting a COVID-19 vaccine had higher aOR of not receiving further doses, suggesting that concerns regarding the vaccination during pregnancy or barriers may persist. Common concerns include vaccine safety, fear of an adverse event for mother and baby, and lack of information on the vaccine [33]. Further qualitive research is required to understand if similar reasons exist in previously vaccinated women who become pregnant.

To our knowledge, this is the first study to investigate incomplete COVID-19 vaccine schedules in individuals with health conditions. Although the presence of health conditions is, generally, associated with increased vaccine acceptance and uptake [9,34], multimorbidity has previously been identified as a risk-factor for being unvaccinated [13]. In general, we found disengagement was lower in those with multimorbidity and health conditions compared to the general population. However, once covariates such as age and sex were adjusted for, individuals with conditions such as thrombosis, or pulmonary embolus, severe mental illness, cirrhosis of the liver, and epilepsy, had higher aOR of not receiving a second dose compared to those without those conditions. Individuals with several other health conditions had higher aOR of not receiving further doses, however, the aORs were small (less than 1.1) therefore these findings may not be clinically relevant. Reasons associated with vaccine hesitancy in people with chronic and underlying health conditions include concerns regarding safety and side effects of vaccination, the low perception of risk from COVID-19, and impact on their disease and/or treatment [35]. It is important to acknowledge logistical barriers that may also reduce accessibility of vaccination. This may include appointment inconvenience, transportation limitations, and social/psychological barriers or communication issues in mass vaccination clinics [36]. These barriers may disproportionately affect individuals with underlying medical conditions [37]. The World Health Organisations 3C's (confidence, complacency, convenience) model for uptake highlights the significance of addressing convenience to improve vaccination rates in these populations [38].

Family and household influences may be an important factor in healthcare decision making, such as engagement in vaccination. To our knowledge, this is the first study associating household adult vaccination status and SARS-CoV-2 positivity to disengagement by an individual from a vaccination programme. Studies have found an association between parental vaccination status and COVID-19 vaccine uptake in children [39], however the influence of unvaccinated adults in the household on vaccine status has been less explored. Our observations suggest that household test positivity post vaccination may play a significant role in vaccination intention. This could be due to perceived lack of vaccine effectiveness, with the individual being positive but not testing or practical challenges of being able to get vaccinated when household members are ill. Further research is needed to examine the relationship between household test positivity and barriers to vaccination.

We observed lower uptake of additional doses after mRNA-1273 compared to ChAdOx1 nCoV-19. A higher likelihood of reactogenicity and adverse events has been observed after vaccination with mRNA-1273[40,41]. Intensity of side effects experienced after vaccination with mRNA-1273 may discourage individuals from pursuing subsequent doses.

Incomplete COVID-19 schedule was higher in more deprived populations. Previous studies have noted lower vaccine uptake in more deprived populations [42]. Factors contributing to this association may include lower health literacy, financial constraints of travel costs, work-related challenges, reduced engagement with healthcare services, and chaotic lifestyles [43]. Addressing vaccination access is crucial to reducing COVID-19 inequalities in deprived populations.

People at higher risk of severe COVID-19 outcomes were more likely to be vaccinated, such as those with health conditions and the elderly [9,44]. Here we identify several groups with higher aOR of not completing the recommended vaccine schedule who are also at higher risk of severe COVID-19 outcomes. A better understanding of the factors influencing vaccination intentions, especially amongst those groups at higher risk of disengagement, will help to inform public health interventions and promote vaccine equity. This is more significant since disparities in vaccine uptake may perpetuate health inequalities in at risk groups. Vaccine hesitancy is complex in nature and can involve attitudes related to conspiracy theories, underestimation of risk, lack of confidence in the vaccine or the safety of the vaccine, and mistrust in authority [45,46]. Interpretation of our findings requires the addition of qualitative research to understand the reasons for vaccine hesitancy and identify barriers to vaccination.

This study has some limitations. Data linkages between vaccination, demographic, hospitalisation admission and testing data are highly accurate and complete allowing for adequate follow-up for most participants in this large cohort. However, some COVID-19 vaccination records may have been inaccurate where individuals received a vaccination outwith the UK or did not notify their GP of migration. This impact will likely have been minor as we included those vaccinated at least once. Health conditions, demographic, socioeconomic and urban/rural category are updated on an ad-hoc basis from GP records. Therefore, data on individuals who had recently moved, not recently attended their GP, or recently diagnosed with a disease of interest may not be identified. Hospitalisation due to a potential AESI identified may also have occurred coincidentally to vaccination. There may be vaccine associated AESI for conditions that were not included in this analysis, were treated outwith hospital, or occurred >28 days post-vaccination.

Table 5
Number and proportion of individuals aged 18 years and above who received a third COVID-19 vaccine between 08 December 2020 and 31 May 2022 in Scotland and the odds of not receiving a third COVID-19 vaccine by QCOVID risk group.

Variable	Dose Three Analysis							
	Vaccinated with dose 2 who were vaccinated with dose 3		Age-sex adjusted rates		Not receiving third dose			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Learning Disabilities								
No	3,225,175	87.93	86.41	86.41—86.41	Reference			
Yes	36,559	86.35	88.61	88.61—88.61	1.16	1.13–1.20	0.77	0.75–0.80
Chronic Kidney Disease								
No/Level 1–2	3,112,269	87.49	86.45	86.45—86.45	Reference			
Yes	150,862	97.67	91.92	91.92—91.92	0.17	0.16–0.70	0.84	0.81–0.87
Atrial Fibrillation								
No	3,160,885	87.64	86.45	86.45—86.45	Reference			
Yes	102,268	97.37	88.45	88.45—88.45	0.19	0.19–0.20	0.90	0.87–0.94
Asthma								
No	2,883,898	88.93	86.31	86.31—86.31	Reference			
Yes	379,255	87.82	87.54	87.54—87.54	1.01	1.00–1.02	0.90	0.90–0.91
Blood Cancer								
No	3,245,543	87.87	86.45	86.45—86.45	Reference			
Yes	17,610	95.78	90.89	90.88—90.9	0.32	0.30–0.34	0.69	0.64–0.74
Cystic Fibrosis								
No	3,222,587	87.81	86.46	86.46—86.46	Reference			
Yes	40,566	96.61	88.86	88.86—88.86	0.26	0.25–0.27	0.98	0.92–1.03
Cerebral Palsy								
No	3,258,431	87.91	86.45	86.45—86.45	Reference			
Yes	4722	91.71	93.09	93.05—93.13	0.66	0.60–0.73	0.51	0.46–0.57
Coronary Heart Disease								
No	3,092,509	87.49	86.48	86.48—86.48	Reference			
Yes	170,644	96.35	84.48	84.48—84.48	0.27	0.26–0.28	0.93	0.91–0.96
Cirrhosis								
No	3,254,151	87.90	86.47	86.47—86.47	Reference			
Yes	9,002	93.58	86.06	86.04—86.08	0.51	0.47–0.55	1.03	0.95–1.13
Congenital Heart Disease								
No	3,247,615	87.01	86.44	86.44—86.44	Reference			
Yes	15,538	89.30	90.21	90.2—90.22	0.87	0.83–0.92	0.76	0.72–0.80
Chronic Obstructive Pulmonary Disease								
No	3,161,792	87.73	86.52	86.52—86.52	Reference			
Yes	101,361	94.14	83.16	83.16—83.16	0.45	0.44–0.47	1.11	1.08–1.14
Dementia								
No	3,244,101	87.86	86.46	86.46—86.46	Reference			
Yes	19,052	97.82	84.55	84.54—84.56	0.16	0.14–0.18	1.08	0.98–1.20
Diabetes								
No	2,296,210	86.07	86.35	86.35—86.35	Reference			
Yes	966,943	72.61	87.01	87.01—87.01	0.50	0.49–0.50	0.88	0.87–0.89
Epilepsy								
No	3,211,966	87.89	86.44	86.44—86.44	Reference			
Yes	51,187	89.65	88.28	88.28—88.28	0.84	0.82–0.87	0.88	0.86–0.91
Prior Fracture of Hip, Wrist, Spine Or Humerus (Fragility Fracture)								
No	3,099,672	87.79	86.48	86.48—86.48	Reference			
Yes	163,481	90.34	85.98	85.98—85.98	0.77	0.75–0.78	1.06	1.04–1.08
Prescribed immunosuppressants								
No	3,261,734	87.91	86.46	86.46—86.46	Reference			
Yes	1,419	93.17	93.1	92.97—93.23	0.53	0.43–0.65	0.57	0.46–0.70
Neurological Condition								
No	3,246,654	87.88	86.45	86.45—86.45	Reference			
Yes	16,499	94.85	91.87	91.86—91.88	0.40	0.37–0.43	0.59	0.55–0.63
Parkinson's Disease								
No	3,254,551	87.89	86.46	86.46—86.46	Reference			
Yes	8,602	97.82	91.97	91.95—91.99	0.16	0.14–0.19	0.81	0.70–0.93
Pulmonary Hypertension								
No	3,257,223	87.90	86.46	86.46—86.46	Reference			
Yes	5,930		90.17	90.14—90.2	0.21	0.18–0.25	0.75	0.64–0.88
Bronchiectasis or Alveolitis								
No	3,242,030	88.21	86.46	86.46—86.46	Reference			
Yes	21,123	96.50	90.84	90.83—90.85	0.26	0.25–0.28	0.78	0.72–0.84
Peripheral Vascular Disease								
No	3,252,973	87.89	86.47	86.47—86.47	Reference			
Yes	10,180	95.25	84.84	84.82—84.86	0.37	0.34–0.40	1.04	0.95–1.14
Stroke								
No	3,161,264	87.68	86.48	86.48—86.48	Reference			
Yes	101,889	96.03	88.32	88.32—88.32	0.30	0.29–0.31	1.07	1.04–1.11
Thrombosis or Pulmonary Embolus								
No	3,227,866	87.85	86.47	86.47—86.47	Reference			
Yes	35,287	94.17	86.29	86.29—86.29	0.45	0.43–0.47	1.02	0.97–1.06

(*continued on next page*)

Table 5 (*continued*)

Variable	Dose Three Analysis							
	Vaccinated with dose 2 who were vaccinated with dose 3		Age-sex adjusted rates		Not receiving third dose			
	N	Uptake (%)	AR (%)	95% CI	UOR	95% CI	AOR	95% CI
Rheumatoid Arthritis or Systemic Lupus Erythematosus								
No	3,186,292	87.77	86.41	86.41—86.41	Reference			
Yes	76,861	94.32	90.79	90.79—90.79	0.43	0.42–0.45	0.70	0.68–0.72
Respiratory Cancer								
No	3,258,606	87.90	86.46	86.46—86.46	Reference			
Yes	4,547	95.69	90.43	90.39—90.47	0.34	0.29–0.39	0.87	0.75–1.00
Severely Mentally Ill								
No	3,248,756	87.91	86.47	86.47—86.47	Reference			
Yes	14,397	88.50	85.4	85.39—85.41	0.96	0.91–1.01	1.02	0.97–1.07

N= Number, AR = Adjusted rate, 95% CI = 95% confidence interval, UOR = Unadjusted odds ratio, AOR = Adjusted odds ratio.

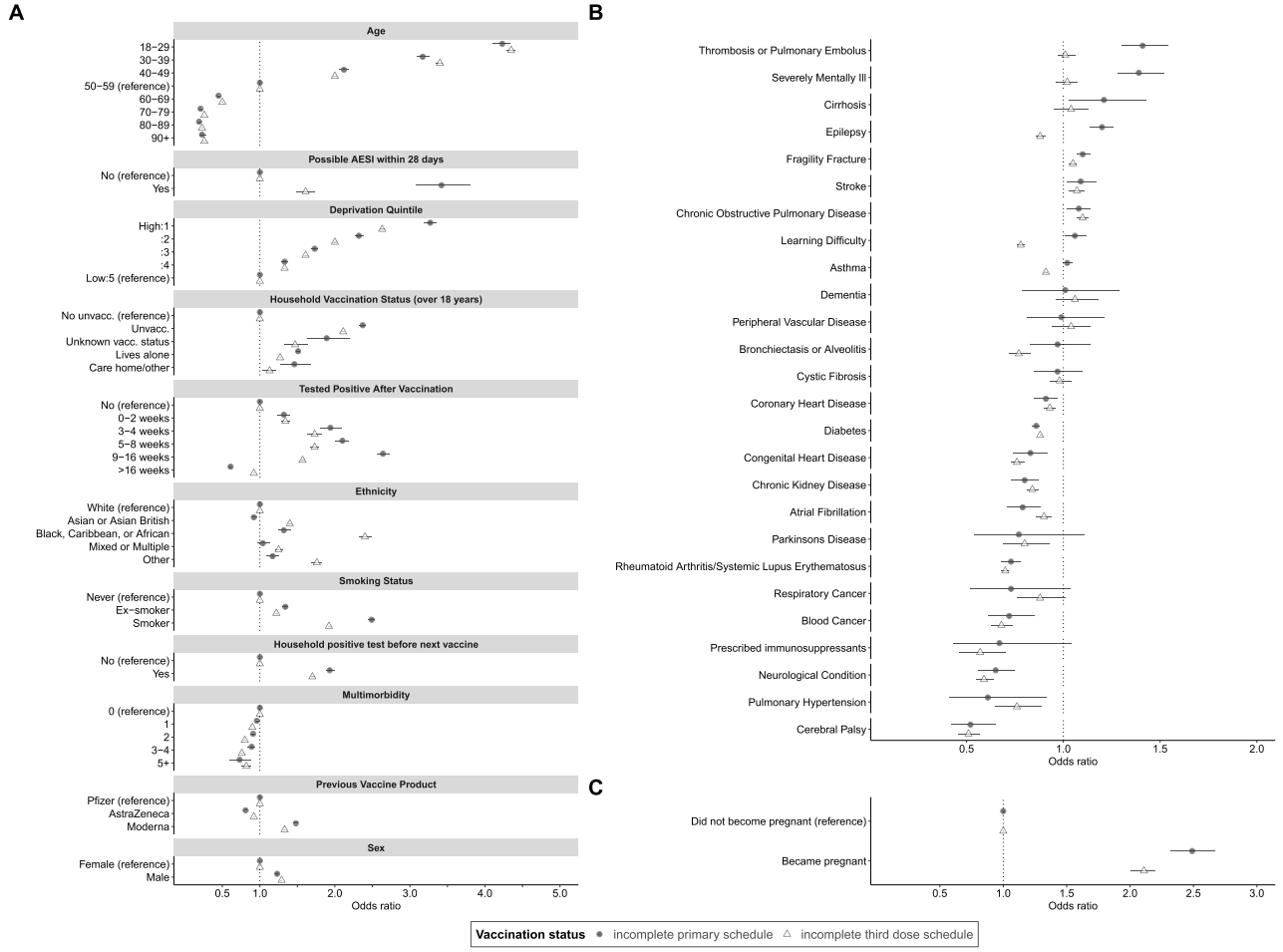

Fig. 3. Adjusted odds ratios of not receiving a second (circle) and third dose (triangle) COVID-19 vaccine in individuals present in 3.7 million adults in Scotland. Three models were created to explore; A) sociodemographic factors, B) clinical factors, and C) women who became pregnant since previous dose. Adjusted odds-ratios and the respective 95% confidence intervals are denoted by circles and black lines. Models adjusted for health board and urban/rural location (not shown). Multimorbidity refers to the number of QCOVID risk groups, individuals may have other health conditions.

Immunocompromised individuals were offered the third dose as part of their primary schedule. We could not identify those who were immunocompromised and therefore offered three primary doses. The analysis identifying predictors of non-uptake of the third dose had a shorter follow up period (9 months) compared to the second dose analysis (16.5 months). However, by this point the majority of those going to get the vaccine had received it.

Community engagement through health professionals plays a key role in forming and maintaining public trust in vaccination [47]. Influenza vaccine uptake was higher in those who received information from medical professionals, compared to those who placed more value in sources such as social media or friends [47]. Our findings can allow medical and public health professionals to target specific groups to address concerns and provide information. Some groups, particularly those from a Black, African, or Caribbean ethnic minority had reduced likelihood of receiving the second and third dose highlighting the need for continued health promotion efforts with these communities.

Table 6
Number and proportion of individuals aged 18 years and above who received a second and third COVID-19 vaccine dose between 8 December 2020 and 31 May 2022 in Scotland and the odds of not completing the COVID-19 vaccine programme by pregnancy status.

Variable	Dose Two Analysis							Dose Three Analysis						
	Vaccinated with dose 1 who were vaccinated with dose 2		Age-sex adjusted rates		Not completing primary schedule			Vaccinated with dose 2 who were vaccinated with dose 3		Age-sex adjusted rates		Not receiving third dose		
	N	% Uptake	AR	95% CI	UOR	95% CI	AOR	95% CI	N	% Uptake	AR	95% CI	UOR	95% CI	AOR	95% CI
Became pregnant	7,107	87.63	90.41	90.39–90.43	2.88	2.67–3.10	2.42	2.25–2.59	6,301	66.06	73.17	73.15–73.19	2.42	2.31–2.52	2.03	1.94- 2.13
Did not become pregnant	551,148	95.02	95.13	95.13–95.13	Reference				974,999	82.00	81.73	81.73–81.73	Reference			

N= Number, AR = Adjusted rate, 95% CI = 95% confidence interval, UOR = Unadjusted odds ratio, AOR = Adjusted odds ratio.

5. Conclusion

This study suggests that age, potential AESI after previous vaccination, socioeconomic status, ethnicity, pregnancy, and previous vaccine product are significant predictors of likelihood to complete the recommended COVID-19 vaccine schedule. Our observations have implications for future vaccination programme strategies by identifying groups for targeted public health messaging and actions. In Scotland, only those with 'at risk' conditions or those aged ≥50 years are eligible for the current COVID-19 2022/23 vaccination programme, and future programmes may only target those at high risk of severe COVID-19 outcomes. Therefore, continued surveillance is required for future vaccination programmes to identify predictors of uptake in eligible groups and evaluate interventions to improve uptake, especially in groups at risk of severe COVID-19 outcomes. This research would be complemented by investigations to improve our understanding of the importance of subsequent vaccination doses for the specific groups identified as being most vaccine hesitant. Additional vaccines may not increase protection in populations at low risk of severe outcomes, such as the young and healthy, and those with high levels of natural immunity [40]. Further research is required to understand the COVID-19 outcomes in those that are sub-optimally vaccinated and how long vaccine protection lasts.

Conflicts of interest: AS has served on a number of UK and Scottish Government COVID-19 Advisory Groups and was a member of AstraZeneca's Thrombotic Thrombocytopenic Taskforce; all of these roles were unremunerated. SVK was co-chair of the Scottish Government's Expert Reference Group on Ethnicity and COVID-19. IR is the adviser of the Croatian Government on the COVID-19 response and this role is unremunerated. CR is a member of SPI-M, Scottish Government Scientific Advisory Committee, MHRA Covid vaccine benefit and risk expert working group.

Ethical Statement: Ethical approval was granted by the National Research Ethics Service Committee, Southeast Scotland 02 (12/SS/0201). Approval for data linkage was granted by the Public Benefit and Privacy Panel for Health and Social Care (1920–0279). Individual written consent was not required for this project.

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Data statement: The data used in this study are sensitive due to individual patient-level data and will not be made publicly available.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2023.07.070.

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