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Impact of the COVID-19 pandemic on timeliness and equity of measles, mumps and rubella vaccinations in North East London: a longitudinal study using electronic health records

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ABSTRACT

Objectives To quantify the effect of the COVID-19 pandemic on the timeliness of, and geographical and sociodemographic inequalities in, receipt of first measles, mumps and rubella (MMR) vaccination.

Design Longitudinal study using primary care electronic health records.

Setting 285 general practices in North East London.

Participants Children born between 23 August 2017 and 22 September 2018 (pre-pandemic cohort) or between 23 March 2019 and 1 May 2020 (pandemic cohort).

Main outcome measure Receipt of timely MMR vaccination between 12 and 18 months of age.

Methods We used logistic regression to estimate the ORs (95% CIs) of receipt of a timely vaccination adjusting for sex, deprivation, ethnic background and Clinical Commissioning Group. We plotted choropleth maps of the proportion receiving timely vaccinations.

Results Timely MMR receipt fell by 4.0% (95% CI: 3.4% to 4.6%) from 79.2% (78.8% to 79.6%) to 75.2% (74.7% to 75.7%) in the pre-pandemic (*n*=33 226; 51.3% boys) and pandemic (*n*=32 446; 51.4%) cohorts, respectively. After adjustment, timely vaccination was less likely in the pandemic cohort (0.79; 0.76 to 0.82), children from black (0.70; 0.65 to 0.76), mixed/other (0.77; 0.72 to 0.82) or with missing (0.77; 0.74 to 0.81) ethnic background, and more likely in girls (1.07; 1.03 to 1.11) and those from South Asian backgrounds (1.39; 1.30 to 1.48). Children living in the least deprived areas were more likely to receive a timely MMR (2.09; 1.78 to 2.46) but there was no interaction between cohorts and deprivation (Wald statistic: 3.44; p=0.49). The proportion of neighbourhoods where less than 60% of children received timely vaccination increased from 7.5% to 12.7% during the pandemic.

Conclusions The COVID-19 pandemic was associated with a significant fall in timely MMR receipt and increased geographical clustering of measles susceptibility in an area of historically low and inequitable MMR coverage. Immediate action is needed to avert measles outbreaks and support primary care to deliver timely and equitable vaccinations.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ We used routine primary care electronic health records available in near real time for an entire population of children registered with all National Health Service general practices in one region of London.
⇒ Coding of routine childhood vaccinations by primary care teams in North East London is enabled by data entry templates with standardised coding enabling high-quality recording of childhood vaccinations at the point of care.
⇒ We used robust statistical methods to investigate inequalities in measles, mumps and rubella timeliness and the impact of the COVID-19 pandemic.
⇒ Ethnic background was not recorded in the primary care electronic health records of more than one-third of children in our study sample.

INTRODUCTION

The COVID-19 pandemic disrupted routine healthcare and services across the UK, through rising COVID-19 infections as well as the introduction of social distancing measures and lockdowns.[1] The UK Joint Committee on Vaccination and Immunisation emphasised the importance of continued receipt of routine vaccinations throughout periods of lockdown.[2]

In the 12 months to March 2021, an average of 90.3% of children scheduled to receive a first measles, mumps and rubella (MMR) vaccination had been vaccinated by 24 months of age in England. This was approximately 0.3% lower than for the same period to March 2020, with average levels in both years well below the WHO coverage target of 95%.[3]

These national averages conceal significant geographical inequity. The most recent annual local authority coverage

data demonstrate that in London, MMR coverage fell from 83.6% to 82.4% at 24 months from 2019 to 2021.[3] These findings indicate significant disruption across routine child vaccination schedules which are worse in regions with historically low uptake,[4] reflecting pre-existing inequalities observed in MMR uptake in the UK[5] resulting in a measles outbreak and loss of measles 'elimination status' in 2019.[6]

Research investigating the impact of the COVID-19 pandemic on routine vaccination schedules found that MMR uptake during April 2020 dropped initially by 42.5% in London in comparison with the same time period during 2019.[7] In addition to reduced vaccination uptake, a recent systematic review has highlighted the consequential impacts on vaccination inequalities during pandemics,[8] identifying four studies which reported that inequalities in routine vaccination coverage worsened during the pandemic compared with pre-pandemic months. A study in Pakistan[9] identified greater reductions in routine vaccination coverage among children whose parents had lower education than children whose parents had received higher educational levels, while a Colombian study[10] found reduced vaccination coverage among children living in rural compared with urban areas. Studies taking place in the USA identified widening inequalities in vaccination coverage during the pandemic by race[11] and Medicaid enrolment.[12]

The findings from this systematic review highlight the importance of understanding the impact of the COVID-19 pandemic on MMR in the UK. Further reductions in MMR uptake will increase the risk of future measles outbreaks, particularly in London where a significant proportion of children start school without the full protection offered by MMR vaccination.[13]

Methods currently used to assess vaccine coverage lack information on timeliness, as well as social, ethnic and geographical inequalities. Because of their retrospective nature, these methods are not actionable. This is important as it has been acknowledged that regional averages conceal geographical clusters of susceptibility in smaller areas which fuel outbreaks.[14] We examined the impact of the COVID-19 pandemic on timeliness of the first MMR vaccination in North East London (NEL). Specifically, we aimed to quantify the impact of COVID-19 on timeliness of the first MMR vaccination and investigate whether inequalities in receipt of timely MMR vaccination and its geographical clustering were amplified during the pandemic. We also aimed to report the number of measles and mumps cases recorded in primary care in NEL occurring during the pandemic period and equivalent pre-pandemic period.

METHODS

Study design and setting

We carried out a longitudinal study using primary care electronic health records (EHRs) from 285 general practices (GPs) in seven geographically contiguous NEL Clinical Commissioning Groups (CCGs): Barking & Dagenham, City & Hackney, Havering, Newham, Redbridge, Tower Hamlets and Waltham Forest. The study protocol can be found in online supplemental file 1 and STrengthening the Reporting of OBservational studies in Epidemiology checklist in online supplemental file 2.

Study population

We defined two cohorts of children eligible to receive their first MMR vaccination between 12 and 18 months of age in the 19 months before and after 23 March 2020—the date at which the first national lockdown commenced in the UK. The pre-pandemic cohort comprised those born between 23 August 2017 and 22 September 2018, and the pandemic cohort those born between 23 March 2019 and 1 May 2020.

Data sources

Pseudonymised data were provided from the NEL Discovery Data Service, which receives primary care EHR data on a daily basis from all GPs in NEL. Demographic and clinical data were extracted for 1 192 630 children born between September 2001 and October 2021, ever registered with a NEL GP and including children who may have died or left the area. Data were extracted on 23 November 2021 and included all clinical events up to 1 November 2021. All data were extracted and managed according to UK National Health Service (NHS) information governance requirements.[15]

Data processing

We identified 519 465 children with a NEL GP registration at the time of their first birthday (online supplemental figure S1) and retained only those eligible for the pandemic and pre-pandemic cohorts (figure 1).

We extracted sociodemographic and geographical data for each child, together with—for each child—all clinical events relating to MMR procedures. Documentation of the processing of MMR events can be found in online supplemental figure S2, tables S1 and S2. Using access to calendar week, month and year of birth we derived a proxy date of birth combining the date of the first day of the week of the calendar week of birth with month and year of birth.

Outcome of interest

We defined timely MMR vaccination as receipt of the first MMR vaccination between 12 and 18 months of age, which is consistent with NHS England's definition of a timely MMR vaccination for the Quality and Outcomes Framework (QOF).[16] A vaccination considered not timely may have been given too early (before 12 months of age), late (after 18 months of age) or not recorded (never or not yet received).

Cases of measles and mumps were identified in primary care EHRs as events with relevant Systematized

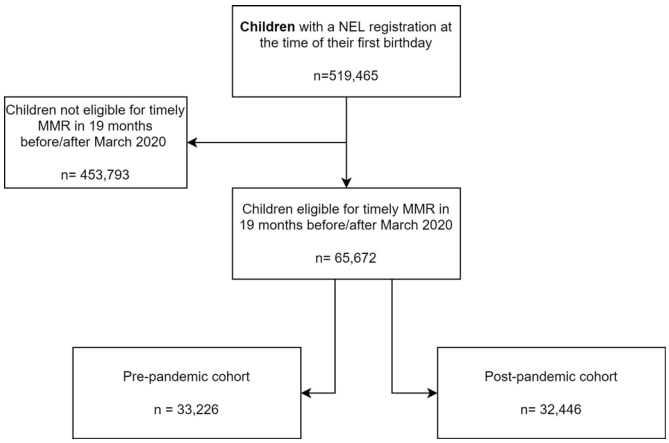

Figure 1 Study sample. MMR, measles, mumps and rubella; NEL, North East London.

Nomenclature of Medicine (SNOMED) Clinical Terms (see online supplemental table S3). Only the first instance of each diagnosis code was retained.

Covariates of interest

We merged 2019 Index of Multiple Deprivation (IMD) rank[17] into the datafile using the 2011 Lower Super Output Area (LSOA)—an area with an average population of 1500 people or 650 households—as the linkage field, and categorised IMD rank into the national quintiles from most to least deprived. Ethnic background was categorised using the NHS classification from information recorded in the primary care record. We grouped ethnic background into four mutually exclusive groups: white ('white British', 'white Irish' or 'any other white background'); black ('black African', 'black Caribbean' or 'any other black background'); South Asian ('Indian', 'Pakistani', 'Bangladeshi' or 'Sri Lankan'); and mixed/other ('any other ethnic background', 'mixed ethnicity', 'Chinese' or 'Asian other'). A missing category was created where ethnicity was not coded in the primary care record.

Statistical analyses

We explored variation in the proportion of children receiving a timely MMR vaccination by cohort, sex, CCG, ethnic background and IMD quintile, and described the differences in the proportion of children receiving timely MMR vaccination in each cohort by these covariates.

For children with a GP-recorded address with an associated LSOA in NEL, we plotted choropleth maps of the proportion of children receiving timely MMR vaccination in each cohort and the change in proportion between the two cohorts by LSOA, to visualise geographical clustering of MMR vaccination timeliness. LSOAs with fewer than 10 eligible children in either the pre-pandemic or pandemic cohorts were suppressed.

We conducted binary logistic regression to estimate the adjusted odds (OR and 95% CI) of timely MMR vaccination after adjustment for covariates. We tested an interaction between cohort and IMD quintile to assess whether COVID-19 had widened inequalities in timely vaccination. All analyses were conducted using Stata (V.MP/15.0).

Patient and public involvement

We involved patients and the public in the communication of study results and dissemination within the local community using accepted principles from the UK Standards for Public Involvement.[18] The aim was to raise awareness of the importance of inequalities in timely childhood vaccinations. We established a patient advisory group, comprising six parents, to co-produce dissemination materials. The patient and public involvement group reflected on vaccination inequalities, the study design and how results were delivered. Participants expressed reservations about the categorisation of ethnic background and whether more granular categories could be used in future research. They discussed communication and visualisation of results. Dissemination of results is ongoing and informed by advice about accessing hard-to-reach and existing community groups.

RESULTS

The pre-pandemic and pandemic cohorts comprised 33 226 (51.3% boys) and 32 446 (51.4% boys) children, respectively (figure 1). The cohorts were similar with respect to demographic characteristics: the majority lived in the most deprived areas and were from diverse ethnic backgrounds (table 1 and online supplemental table S4). Timely MMR receipt was 4.0% (95% CI: 3.4% to 4.6%) lower in the pandemic compared with the pre-pandemic cohort.

Children from white, mixed/other and black ethnic backgrounds had the lowest—and children from South Asian ethnic backgrounds the highest—percentage of timely MMR receipt (table 2). There was a strong positive gradient in vaccination timeliness by IMD quintile: relative to those living in the least deprived quintile, the proportion of children receiving a timely MMR vaccination was 10.8% (8.6% to 13.0%) and 14.3% lower (11.8% to 16.8%) in the pre-pandemic and pandemic cohorts, respectively.

The proportion of LSOAs where fewer than 60% of children received a timely MMR vaccination increased from 7.5% (90) to 12.7% (153) in the pandemic cohort (figure 2A,B). These were clustered in parts of City & Hackney, Newham, Redbridge, and Barking & Dagenham. Almost half of LSOAs where fewer than 60% of children received timely MMR vaccinations were assigned to the most deprived IMD quintile compared with one-third in the pre-pandemic cohort (online supplemental table S5). The proportion of children receiving a timely MMR vaccination fell during the pandemic period in 634 (52.7%) out of 1203 LSOAs (figure 3), and these were predominantly located in Tower Hamlets and City & Hackney. The proportion increased in 367 LSOAs (30.5%) and remained the same in 13 (1.1%).

Table 1 Sample characteristics

	Pre-pandemic cohort (n=33 226)			Pandemic cohort (n=32 446)			All (n=65 672)		
	n	%	95% CI	n	%	95% CI	n	%	95% CI
Sex									
Male	17 055	51.3	50.8 to 51.9	16 665	51.4	50.8 to 49.2	33 720	51.4	51.0 to 51.7
Female	16 169	48.7	48.1 to 49.2	15 781	48.6	48.1 to 49.2	31 950	48.6	48.3 to 49.0
Other	2			0			2		
CCG									
Barking & Dagenham	3916	11.8	11.4 to 12.1	3819	11.8	11.4 to 12.1	7735	11.8	11.5 to 12.0
City & Hackney	4771	14.4	14.0 to 14.7	4631	14.3	13.9 to 14.7	9402	14.3	14.1 to 14.6
Havering	3684	11.1	10.8 to 11.4	3657	11.3	10.9 to 11.6	7341	11.2	10.9 to 11.4
Newham	6458	19.4	19.0 to 19.9	6210	19.1	18.7 to 19.6	12 668	19.3	19.0 to 19.6
Redbridge	4971	15.0	14.6 to 15.3	4793	14.8	14.4 to 15.2	9764	14.9	14.6 to 15.1
Tower Hamlets	4605	13.9	13.5 to 14.2	4598	14.2	13.8 to 14.6	9203	14.0	13.8 to 14.3
Waltham Forest	4821	14.5	14.1 to 14.9	4738	14.6	14.2 to 15.0	9559	14.6	14.3 to 14.8
Ethnic background									
White	9579	28.8	28.3 to 29.3	8938	27.6	27.1 to 28.0	18 517	28.2	27.9 to 28.5
Mixed and other	3813	11.5	11.1 to 11.8	3766	11.6	11.3 to 12.0	7579	11.5	11.3 to 11.8
South Asian	5881	17.7	17.3 to 18.1	5802	17.9	17.5 to 18.3	11 683	17.8	17.5 to 18.1
Black	2054	6.2	5.9 to 6.4	1992	6.1	5.9 to 6.4	4046	6.2	6.0 to 6.3
Missing	11 899	35.8	35.2 to 36.3	11 948	36.8	36.3 to 37.4	23 847	36.3	35.9 to 36.7
IMD quintile									
Most deprived	12 436	37.4	36.9 to 38.0	11 995	37.0	36.4 to 37.5	24 431	37.2	36.8 to 37.6
2	13 464	40.5	40.0 to 41.1	13 306	41.0	40.5 to 41.5	26 770	40.8	40.4 to 41.1
3	4533	13.6	13.3 to 14.0	4400	13.6	13.2 to 13.9	8933	13.6	13.3 to 13.9
4	1883	5.7	5.4 to 5.9	1956	6.0	5.8 to 6.3	3839	5.9	5.7 to 6.0
Least deprived	847	2.6	2.4 to 2.7	754	2.3	2.2 to 2.5	1601	2.4	2.3 to 2.6
Missing	63	0.2	0.1 to 0.2	35	0.1	0.1 to 0.2	98	0.2	0.1 to 0.2
Timely MMR vaccination*									
Yes	26 315	79.2	78.8 to 79.6	24 402	75.2	74.7 to 75.7	50 717	77.2	76.9 to 77.5
No	6911	20.8	20.4 to 21.2	8044	24.8	24.3 to 25.3	14 955	22.8	22.5 to 23.1
Early	180	0.5	0.5 to 0.6	120	0.4	0.3 to 0.4	300	0.5	0.4 to 0.5
Late	1678	5.1	4.8 to 5.3	932	2.9	2.7 to 3.1	2610	4.0	3.8 to 4.1
Not yet received	5053	15.2	14.8 to 15.6	6992	21.5	21.1 to 22.0	12 045	18.3	18.0 to 18.6

*Receipt of first MMR vaccination between 12 and 18 months of age. Not timely is further broken down into three groups: early (before age 12 months), late (after age 18 months) and not yet received.
CCG, Clinical Commissioning Group; IMD, Index of Multiple Deprivation; MMR, measles, mumps and rubella.

After adjustment, timely MMR receipt was less likely in the pandemic cohort (0.79; 0.76 to 0.82), children from black (0.70; 0.65 to 0.76), mixed/other (0.77; 0.72 to 0.82) or with missing (0.77; 0.74 to 0.81) ethnic backgrounds, and more likely in girls (1.07; 1.03 to 1.11) and those from South Asian backgrounds (1.39; 1.30 to 1.48). Children living in the least deprived areas were more likely to receive a timely MMR (2.09; 1.78 to 2.46; Wald test statistic: 201.66; p<0.0001; figure 4 and online supplemental table S6), but there was no interaction between cohorts and deprivation (Wald statistic: 3.44; p=0.49). Relative to children registered with a GP in Newham, timely MMR receipt was less likely among children in Barking & Dagenham (0.88; 0.82 to 0.94), City & Hackney (0.67; 0.63 to 0.71) or Redbridge (0.69; 0.64 to 0.73) and more likely among those registered to a GP in Havering (1.53; 1.40 to 1.66), Tower Hamlets (1.52; 1.42 to 1.64) and Waltham Forest (1.21; 1.14 to 1.30).

In NEL, there were 20 measles and 34 mumps cases recorded in primary care during the pandemic period,

Table 2 Proportion of children with timely MMR vaccination* in each cohort, and the percentage point difference between pre-pandemic and pandemic cohorts, by sociodemographic characteristics

	Pre-pandemic cohort (n=26 315)			Pandemic cohort (n=24 402)			Percentage point difference†	
	n	%	95% CI	n	%	95% CI	%	95% CI
Sex								
Male	13 362	78.3	77.7 to 79.0	12 480	74.9	74.2 to 75.5	–3.4	–4.3 to –2.5
Female	12 953	80.1	79.5 to 80.7	11 922	75.5	74.9 to 76.2	–4.6	–5.5 to –3.7
CCG								
Barking & Dagenham	2999	76.6	75.2 to 77.9	2725	71.3	69.9 to 72.8	–5.3	–7.3 to –3.3
City & Hackney	3403	71.3	70.0 to 72.6	2897	62.6	61.2 to 63.9	–8.7	-10.6 to –6.8
Havering	3205	87.0	85.9 to 88.0	3095	84.6	83.4 to 85.8	–2.4	–4.0 to –0.8
Newham	5077	78.6	77.6 to 79.6	4717	76.0	74.9 to 77.0	–2.6	–4.1 to –1.1
Redbridge	3713	74.7	73.5 to 75.9	3483	72.7	71.4 to 73.9	–2.0	–3.7 to –0.3
Tower Hamlets	3977	86.4	85.3 to 87.3	3737	81.3	80.1 to 82.4	–5.1	–6.6 to –3.6
Waltham Forest	3941	81.7	80.6 to 82.8	3748	79.1	77.9 to 80.2	–2.6	–4.2 to –1.0
Ethnic background								
White	7865	82.1	81.3 to 82.9	6874	76.9	76.0 to 77.8	–5.2	–6.4 to –4.0
Mixed and other	2872	75.3	73.9 to 76.7	2641	70.1	68.6 to 71.6	–5.2	–7.2 to –3.2
South Asian	4966	84.4	83.5 to 85.3	4824	83.1	82.2 to 84.1	–1.3	–2.6 to 0.0
Black	1517	73.9	71.9 to 75.7	1374	69.0	66.9 to 71.0	–4.9	–7.7 to –2.1
Missing	9095	76.4	75.7 to 77.2	8689	72.7	71.9 to 73.5	–3.7	–4.8 to –2.6
IMD quintile								
Most deprived	9710	78.1	77.3 to 78.8	8779	73.2	72.4 to 74.0	–4.9	–6.0 to –3.8
2	10 523	78.2	77.5 to 78.8	9865	74.1	73.4 to 74.9	–4.1	–5.1 to –3.1
3	3675	81.1	79.9 to 82.2	3437	78.1	76.9 to 79.3	–3.0	–4.7 to –1.3
4	1628	86.5	84.8 to 87.9	1649	84.3	82.6 to 85.9	–2.2	–4.4 to 0.0
Least deprived	753	88.9	86.6 to 90.8	660	87.5	85.0 to 89.7	–1.4	–4.6 to 1.8
Missing	26	41.3	29.9 to 53.7	12	32.3	20.6 to 51.2	–9.0	–28.7 to 10.7

*Receipt of MMR vaccination between 12 and 18 months of age.
†Proportion receiving timely MMR vaccination in pandemic cohort minus the proportion receiving timely MMR vaccination in the pre-pandemic cohort.
CCG, Clinical Commissioning Group; IMD, Index of Multiple Deprivation; MMR, measles, mumps and rubella.

compared with 325 and 140, respectively, in the equivalent pre-pandemic period (online supplemental table S7).

DISCUSSION

Summary of key findings

In the period preceding the COVID-19 pandemic in NEL, only 79% of children received their first MMR vaccination on time; this proportion fell by an average of 4% during the pandemic. The gap between the most and least deprived areas increased by 3.5% during the pandemic period. While this relative inequality did not appear to worsen during the pandemic, these average figures conceal marked inequity at a lower geographical level: the percentage of LSOAs, where fewer than 60% of children received their MMR on time increased from 7.5% to 12.7% in the pandemic, particularly in the most deprived LSOAs. Hence, delayed receipt of MMR is geographically clustered in more deprived neighbourhoods, and this has worsened during the pandemic. These findings are in an area of London where no CCG has met the WHO MMR target of 95% coverage.[3] In the absence of national data, our analyses show for the first time how far this region of London is from achieving the new QOF target for MMR timeliness of 90%–95%.[16]

Strengths and limitations

We used routine primary care EHRs available in near real time for an entire population of children registered with all NHS GPs in one region of London. We have been able to demonstrate—in a geographically contiguous area—neighbourhoods with very high proportions of children who are not immunised promptly. These results further

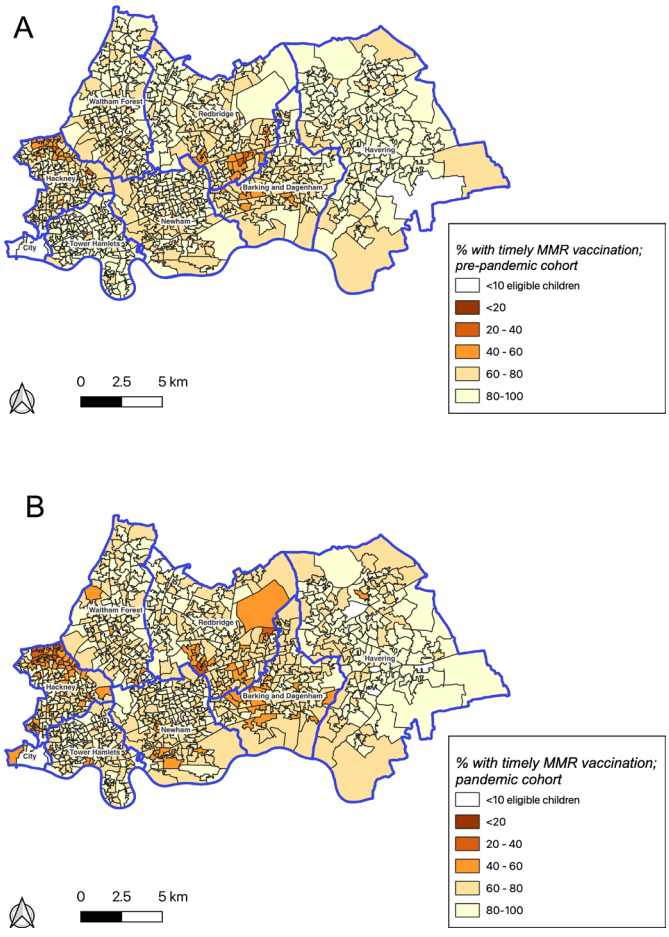

Figure 2 (A) Proportion of children receiving timely MMR vaccination in the pre-pandemic cohort, by 2011 LSOA (B) Proportion of children receiving timely MMR vaccination in the pandemic cohort, by 2011 LSOA. MMR, measles, mumps and rubella; LSOA, lower super output area of the child's home accress, as recorded in their general practice electronic health record.

highlight the inequalities in vaccination timeliness and infection risks experienced by poorer children, their families and communities.

Coding of routine childhood vaccinations by primary care teams in NEL is enabled by data entry templates with standardised coding enabling high-quality recording of childhood vaccinations at the point of care. We used robust statistical methods to investigate inequalities in MMR timeliness and the impact of the COVID-19 pandemic.

Limitations include missing ethnic codes in 36% of the cohort. Our analyses suggest that those with missing ethnicity were less likely to receive a timely MMR vaccine during the pandemic and highlight the importance of improving routine recording of ethnicity in primary care. While our study has focused on timeliness of the first MMR vaccination, it is important to recognise that two doses of MMR are essential for full protection.[19] Additional research investigating timeliness of the second MMR vaccination would further our understanding and

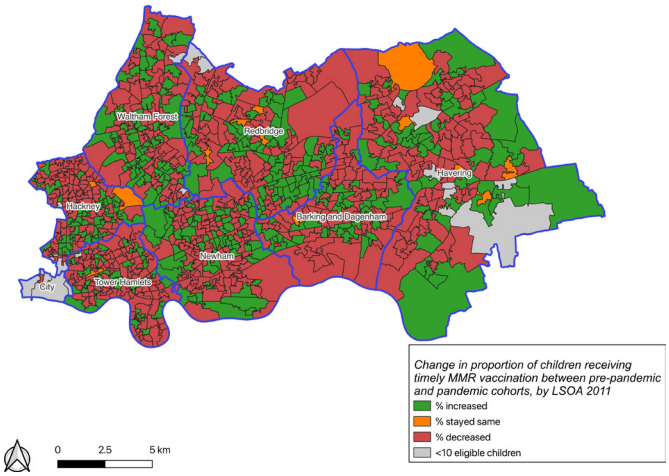

Figure 3 Change[1] in the proportion of children receiving timely MMR vaccination between pre-pandemic and pandemic cohorts, by 2011 LSOA. [1]Proportion receiving timely MMR vaccination in pandemic cohort minus the proportion receiving timely MMR vaccination in the pre-pandemic cohort. MMR, measles, mumps and rubella; LSOA, lower super output area of the child's home address, as recorded in their general practice electronic health record.

improve identification of children with increased measles susceptibility.

Comparison with existing literature

Our findings align with trends indicating a global decrease in uptake of MMR vaccination, both in developing and developed countries.[10 20 21] Some studies reported a decline in uptake of more than 50% during the height of the first wave of the pandemic.[22–24] Globally, measles-containing vaccine coverage estimates were 7.9% lower than expected had there been no COVID-19 pandemic, affecting an estimated 8.9 million children.[25] In England, initial reductions in the number of children receiving their first MMR were followed by a short period of recovery, compared with the same period in 2019, despite continued physical distancing measures remaining in place.[26] However, this increase was short-lived, and the weekly count of children receiving their MMR vaccination in 2020 remained consistently lower or the same as in 2019 for the rest of 2020. Our findings may be explained in part by evidence from qualitative research studies demonstrating that a transition to remote consultations during the pandemic caused some confusion for parents around attending services for routine vaccination.[4] Internationally, fear of COVID-19 exposure in healthcare settings was also found to play a large role in decreased vaccination uptake,[25 27 28] despite evidence that the risk to benefit ratio was in favour of continuing vaccination delivery during the pandemic.[29]

The link between childhood vaccination inequalities and ethnicity has been explored in other studies, demonstrating evidence of reduced timeliness in certain ethnic groups.[30] However, there is heterogeneity within these results according to geographical area of interest.[31] We

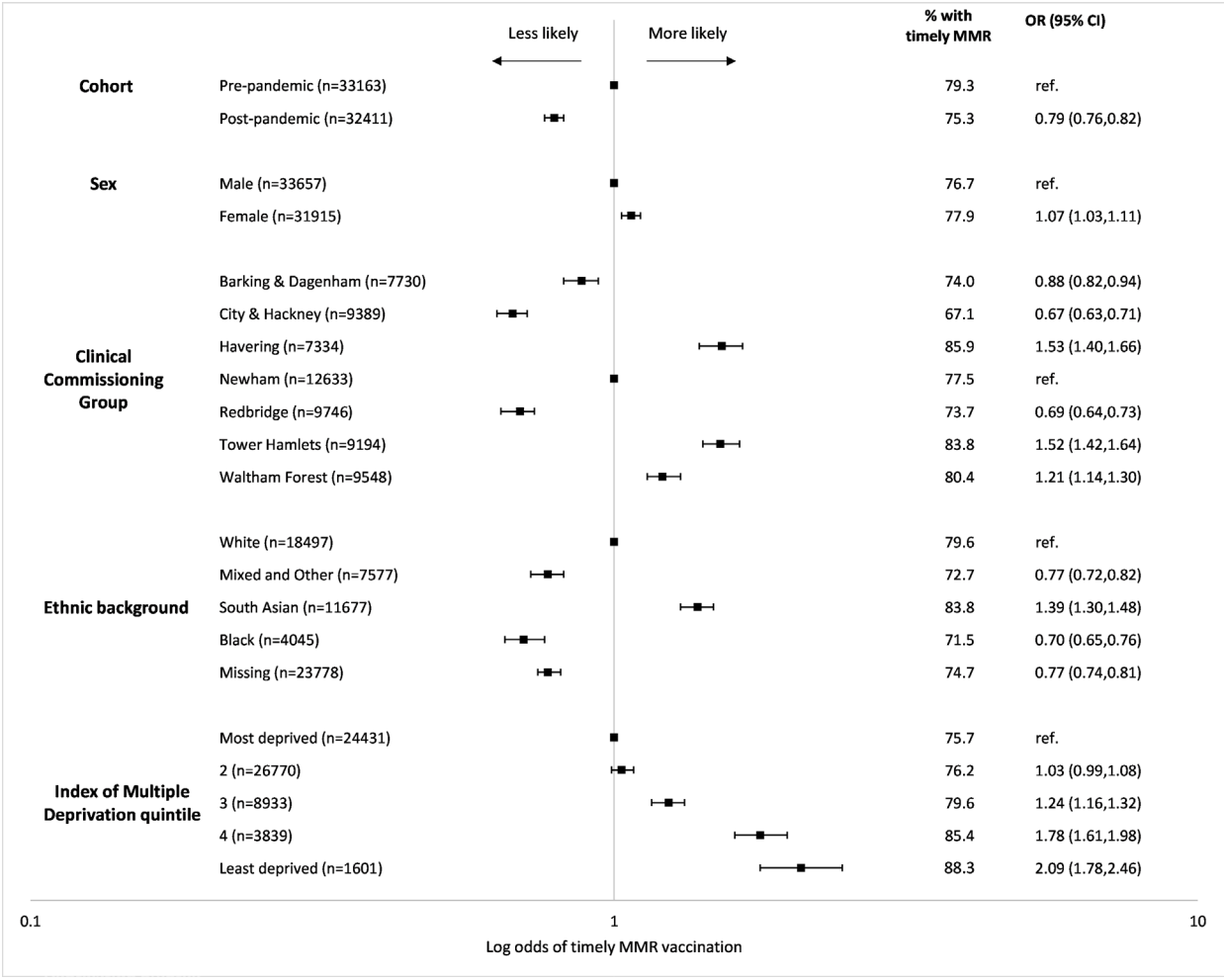

Figure 4 Adjusted log odds of timely MMR vaccination.[1] [1]Model mutually adjusting for cohort, sex, Clinical Commissioning Group, ethnic background and Index of Multiple Deprivation quintile. MMR, measles, mumps and rubella; OR, odds ratio; CI, confidence interval.

found that children from black and mixed/other ethnic backgrounds were less likely to receive timely vaccination, broadly consistent with findings from studies of COVID-19 vaccination uptake which have shown lowest uptake among people from black ethnic backgrounds.[32 33] Additional qualitative evidence suggests women from minority ethnic backgrounds were more likely to find it difficult to access and felt less safe accessing vaccinations for their babies during the COVID-19 pandemic.[34]

Relationships between socioeconomic deprivation and vaccination timeliness appear to be more consistent. A study in Scotland examining vaccination inequity and timeliness demonstrates that the most deprived decile experienced a nearly 50% increased risk of delayed vaccination relative to the least deprived decile for both doses of MMR in the years leading up to the pandemic.[35] Despite this, and in contrast to England, vaccination uptake rose significantly across the first lockdown period in Scotland, with 7000 more children receiving timely routine vaccinations compared with the previous year.[36] The authors of this study speculate that greater flexibility in working patterns offered to many parents during the lockdown period may have increased the accessibility of vaccination appointments.

Our findings are consistent with existing evidence based on Cover of Vaccination Evaluated Rapidly Programme data which confirm that London has a longstanding and disproportionately lower MMR uptake relative to the rest of the UK.[3 37] There is recognised variation between different CCGs in NEL, with lowest uptake in City & Hackney. While particular cultural beliefs held by the Charedi Jewish population in City & Hackney are known to influence uptake of the MMR vaccination,[38] recent evidence suggests that difficulties in accessing vaccination services are also an important factor in this community.[39] The factors responsible for differences between the other CCGs merit further investigation.

Mapping measles vaccinations and outbreaks geospatially enables more granular identification of neighbourhoods requiring focused interventions.[40] Our choropleth maps demonstrate clustering of delayed MMR vaccination in more deprived neighbourhoods—these findings align with previous studies mapping measles outbreak susceptibility[5] and underscore the importance of actionable

real-time information on vaccine timeliness to avert further outbreaks of measles. Our geographical analyses identified an increase in the proportion of children receiving a timely MMR vaccination during the pandemic period in almost one-third of NEL LSOAs. This finding may reflect the innovative measures implemented in some London GPs throughout the pandemic, including vaccinating outside of practice buildings and drive-through services, which may have made routine vaccination more accessible to families.[41]

Our study did not identify an increase in inequity during the pandemic by an area-level measure of deprivation. This is in contrast to findings from Michigan, USA, where the difference in proportion of Medicaid-enrolled children with up-to-date vaccination coverage compared with children not enrolled in Medicaid with up-to-date vaccination coverage increased during the pandemic.[12] This difference is likely to reflect differences in UK and US healthcare systems, as well as the use of an area-level indicator of derivation compared with an individual-level indicator in an area of London with high levels of area-level deprivation.

Implications for research, policy and practice

Gaps in MMR vaccination coverage increase measles susceptibility, and in 2019, there were 800 000 confirmed cases of measles globally.[42] Measles outbreaks have occurred in 2021 in at least half of the 26 countries that suspended their measles vaccination programmes.[29 42 43] There is evidence that the introduction of social distancing measures, school closures and travel restrictions reduced exposure to vaccine-preventable childhood infections.[44] In an analysis of English hospital admissions, there was a 90% and a 53% reduction in hospital admissions for measles and mumps, respectively, among children aged 0–14 years in the pandemic period compared with the preceding 3-year average, although this study was unable to examine infections managed in primary care.[44] In NEL, we identified 20 measles and 34 mumps cases in primary care during the pandemic period, compared with 325 and 140, respectively, in the equivalent pre-pandemic period.

With a reduction in infection and exposure to infection, measles vaccination may receive less priority in a healthcare system already facing multiple challenges.[45] Awareness and retention of existing WHO targets are critical to prevent measles outbreaks, especially given that measles is the most infectious virus, with a reproduction number of 12–18.[46] The need for targeted public health interventions around routine childhood vaccinations in the context of the pandemic has been recognised internationally,[47 48] as well as in England where a recent campaign by NHS England is encouraging parents of 740 000 children who are not fully vaccinated against MMR to make appointments with their GP.[49] There is strong evidence to support the effectiveness of primary care-led quality improvement programmes to improve vaccine uptake.[37] National measures to tackle these inequalities include NHS England's QOFs to incentivise timely routine childhood vaccinations in primary care.[50] In London, a primary care-led quality improvement programme has been launched to tackle inequalities in timeliness of routine preschool childhood vaccinations.[51]

CONCLUSION

Routine vaccination schedules have been disrupted during the COVID-19 pandemic. Our study adds important new evidence of the impact on timeliness of MMR vaccinations, and demonstrates unwarranted variation by neighbourhood, ethnicity and deprivation. These data provide further evidence to prioritise quality improvement and catch-up campaigns to achieve herd immunity and prevent measles outbreaks. They provide actionable information in populations and geographies experiencing significant health inequalities.

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Contributors CD and JR obtained funding for the study. NF and CD conceptualised and designed the analyses. AG, ID and ZA provided guidance for specifying clinical codes. CW and KH extracted data. MM carried out the literature search. NF conducted the analyses, generated tables and figures and drafted the initial manuscript. GH produced the choropleth maps. All authors contributed to the interpretation of analyses and reviewed and revised the manuscript. All authors were involved in writing the paper and had final approval of the submitted and published manuscript. CD is the guarantor and accepts full responsibility for the conduct of the study, had access to the data and controlled the decision to publish.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not required.

Ethics approval This study was approved by the Discovery board for service evaluation (measuring what standard of care this service achieved) and analysed routinely acquired de-identified data; hence, no research ethics committee approval was required by the Health Research Authority.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Access to general practice data is enabled by data sharing agreements between the Discovery Data Service and general practice data controllers. The Discovery Programme Board has approved data access by the REAL Child Health Programme team for research on the condition that it is not onwardly shared.

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COVID-19 and childhood MMR immunisation study protocol

Preliminary title: Assessing the impact of the COVID-19 pandemic on timeliness of MMR uptake in east London: cross-sectional analysis of primary care electronic health records

Writing group: Nicola Firman, Milena Marszalek, Ana Gutierrez, Kate Homer, Crystal Williams, Gill Harper, Isabel Dostal, Zaheer Ahmed, John Robson, Carol Dezateux

Background/rationale

The COVID-19 pandemic has disrupted routine health care and services across the UK, through rising COVID infections as well as the introduction of social distancing measures and lockdowns.(1) The United Kingdom (UK) Joint Committee on Vaccination and Immunisation (JCVI) has emphasised the importance of children continuing to receive routine childhood vaccinations according to the national schedule throughout periods of lockdown.(2)

In the UK, childhood vaccine coverage is routinely assessed quarterly using the COVER (Cover of vaccination evaluated rapidly) programme for children who have reached their first, second, or fifth birthdays. Given the timing of data extractions for COVER, the UK Health Security Agency (HAS) has indicated that this system cannot provide reliable information of the impact of the pandemic on vaccine coverage for England. However, evidence suggests that vaccine coverage measured at 24 months among children scheduled to receive Measles, Mumps and Rubella (MMR) vaccination from March 2020 onwards in England was 90.3%, around 0.3% lower than 2019, with average levels in both years well below the WHO coverage target of 95%.(2, 3) This is broadly in line with data from approximately 38% of GP practices in England, which suggests that vaccination counts for MMR vaccine were 2.1% lower by the end of 2020 than for the equivalent period in 2019. Qualitative studies in the UK looking at attitudes towards routine vaccination during the pandemic report parental fear of attending routine vaccination appointments, reduced concern about catching vaccine-preventable diseases during lockdown, and routine appointment re-scheduling. These findings support emerging research that demonstrates disruption across routine child vaccination schedules.(4)

The measures currently used lack information on vaccination timeliness, impacts on existing vaccine coverage inequalities and do not include areas of historic MMR low uptake. This is important as it has been acknowledged that area-level averages conceal geographical clusters of susceptibility which fuel outbreaks.(5) A systematic review found that there is currently no published literature looking at both routine vaccination schedule disruption and consequential impacts on vaccination inequalities during pandemics.(6) More specific literature exists around uptake trends for particular vaccinations - Macdonald et al. demonstrated that MMR uptake during April 2020 dropped by 42·5% in London in comparison to the same time period during 2019.(7) Overall, MMR uptake decreased by 19.8% in England, before recovering over the following months.(8) Most recent local authority coverage data demonstrates that on London, MMR rates have fallen from 83.6% to 82.4% at 24 months from 2019-2021.(9) Areas previously demonstrating lower MMR uptake were worst affected, including London and the Midlands.(7) UK Cover of vaccination evaluated rapidly (COVER) reports look at vaccine coverage at 12, 24 months, and five years, but do not encompass timeliness measures.

These trends reflect pre-existing inequalities observed in MMR uptake in the UK.(10) Historically, the UK lost its measles 'elimination status' in 2019 due to consistently low MMR uptake.(11) Further reduction in MMR vaccinations will increase the risk of measles outbreaks, particularly in London where a significant proportion of children start school without the full protection offered by MMR vaccination.(12)

Objectives

This protocol sets out to understand the wider impact of COVID-19 on timeliness of MMR vaccinations in seven east London Clinical Commissioning Groups (CCGs). Specifically:

1. To understand the impact of COVID-19 and periods of lockdown on MMR vaccination timeliness
2. To describe geographical clustering of MMR vaccination timeliness
3. To investigate if COVID-19 has amplified inequalities in receipt of timely MMR vaccination

Methods

Study design

A cross-sectional study using primary care electronic health records (EHRs) from child patients registered at 285 general practices in seven geographically contiguous east London CCGs: Barking & Dagenham, City & Hackney, Havering, Newham, Redbridge, Tower Hamlets, and Waltham Forest.

Study sample

The study population will include all children eligible to receive their first MMR vaccination at age 12 to 18 months old, respectively, in the 19 months before and after 23rd March 2020. All children ever registered at one of the 285 general practices between September 2001 and October 2021 will be included.

Data

Data will be extracted from the North East London (NEL) Discovery Data Service (DDS) which receives primary care electronic health record data on a daily basis from all general practices in NEL, on 23rd November 2021. Events recorded up until 1st November 2021 will be included. All data will be extracted and managed according to UK NHS information governance requirements.

We will analyse person-level data for children born between 22nd August 2017 and 22nd September 2018 (pre-pandemic cohort) and 23rd March 2019 and 1st May 2020 (pandemic cohort). These children would be eligible to receive timely MMR vaccination between 12 and 18 months of age in the 19 months before and after England entered the first lockdown on 23rd March 2020, respectively. For each child, the person-level dataset will contain: a pseudonymised person identifier; calendar week, month and year of birth; ethnic background; sex; 2011 lower super output area (LSOA) of the child's address; CCG; MMR clinical code (Read or SNOMED); and date of MMR vaccination. To avoid disclosure of identifiable data, a proxy date of birth will be derived by assigning the week commencing date using the calendar week and year of birth. Consequently, date of birth could be up to six days earlier than the child's actual date of birth. We will merge 2015 Index of Multiple Deprivation (IMD) score and rank(13) into the datafile using LSOA as the linkage field, and categorise IMD rank into quintiles from most to least deprived.

Following guidance from the Green Book, MMR vaccinations given before a child's first birthday will be ignored.(14) Where available, subsequent MMR records will be treated as the child's first vaccination, otherwise early MMR vaccinations will be retained in the dataset and later considered as "not timely".

The following records will be excluded from analyses:

- Records with an MMR clinical code but no date
- Exact duplicate records
- Duplicate records where the date is the same but MMR clinical code differs
- Latter of multiple MMR events

Statistical methods

We will identify timely MMR vaccination among children aged between 12 and 18 months when they received their MMR vaccination. We will explore variation in the proportion of children receiving timely MMR vaccination by cohort, sex, CCG, ethnic background and IMD quintile, and investigate differences in the proportion of children receiving timely MMR vaccination in each cohort, by these covariates.

To describe geographical clustering of MMR vaccination timeliness we will plot in choropleth maps the proportion of children receiving timely MMR vaccination in each cohort, by LSOA.

We will conduct binary logistic regression to estimate the odds (odds ratio [OR] and 95% CI) of timely MMR vaccination after adjustment for covariates and, to assess whether COVID-19 has widened inequalities in timely vaccination, explore an interaction between cohort and IMD quintile.

Ethics

This study was approved by the Discovery board for service evaluation (measuring what standard of care this service achieved) and analysed routinely acquired de-identified data: hence no research ethics committee approval was required by the Health Research Authority. Access to general practice data is enabled by data sharing agreements between the Discovery Data Service and general practice data controllers. The Discovery Programme Board has approved data access by the REAL Child Health programme.

Strengths and limitations

Strengths of this study include:

- Use of person-level data to comprehensively document the impact of COVID-19 on timely MMR vaccine uptake and coverage
- EHR from seven geographically contiguous CCGs, serving a whole population with a large sample size, including children who have left/deregistered from a practice in NEL, or died
- Access to historic data "pre-pandemic" cohort to use as control group
- Implementation of robust statistical methods

Limitations of this study include:

- Use of calendar week of birth to generate a proxy date of birth
- Primary purpose of EHRs is not for research – so it is possible there will be some data quality issues
    - Large proportions of children with missing ethnic background recorded in their EHR

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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #/in section
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Title
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	Introduction
Methods			
Study design	4	Present key elements of study design early in the paper	Methods – study design and setting
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Methods – study design and setting
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Methods – study population
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Methods – outcome of interest
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Methods – covariates of interest
Bias	9	Describe any efforts to address potential sources of bias	Methods – statistical analyses
Study size	10	Explain how the study size was arrived at	Methods – data processing and Supplementary file 3 Figure S2
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Methods – covariates of interest
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Methods – statistical analyses
		(*b*) Describe any methods used to examine subgroups and interactions	Methods – statistical analyses
		(*c*) Explain how missing data were addressed	Methods – covariates of interest and statistical analyses

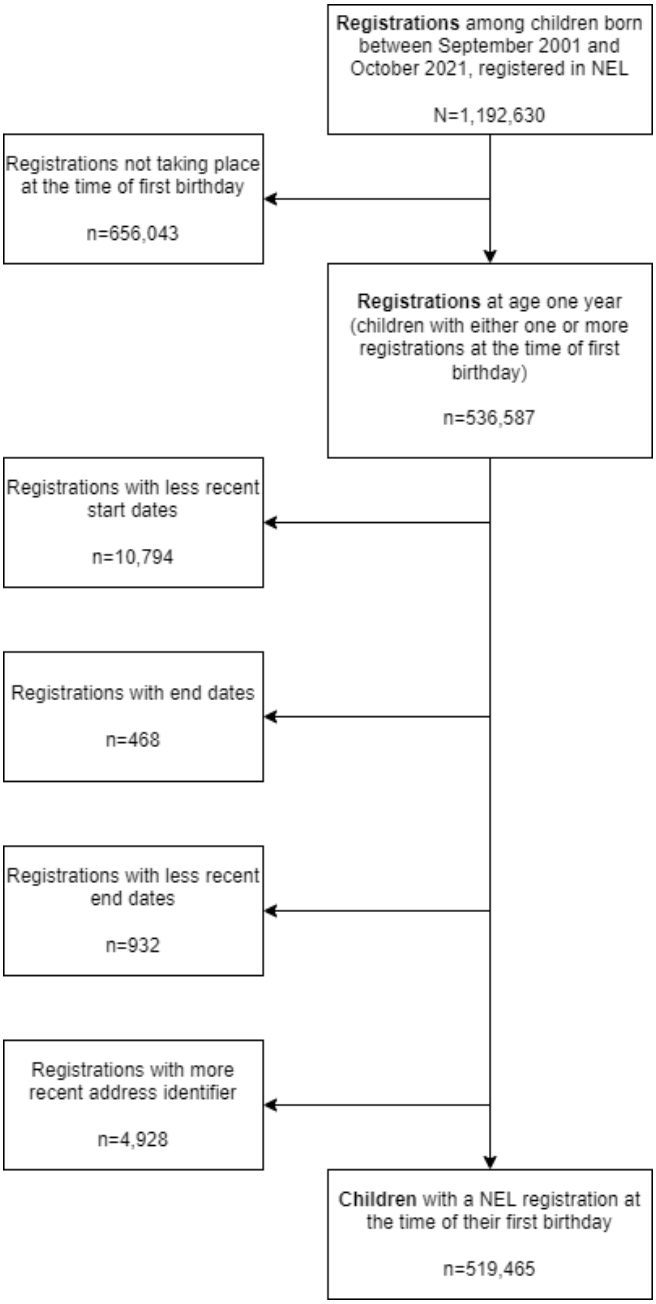
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Results and Supplementary file 3 Figure S2
		(b) Give reasons for non-participation at each stage	Supplementary file 3 Figure S2
		(c) Consider use of a flow diagram	Supplementary file 3 Figure S2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
Outcome data	15*	Report numbers of outcome events or summary measures	Table 2
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Supplementary file 3 Table S5 and Figure 4
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Results
Discussion			
Key results	18	Summarise key results with reference to study objectives	Discussion – summary of key findings
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Discussion – strengths and limitations
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Discussion – implications for research, policy and practice
Generalisability	21	Discuss the generalisability (external validity) of the study results	Discussion – comparison with existing literature
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Funding

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Supplementary tables and figures

Figure S1 – Identifying registrations at the time of first birthday

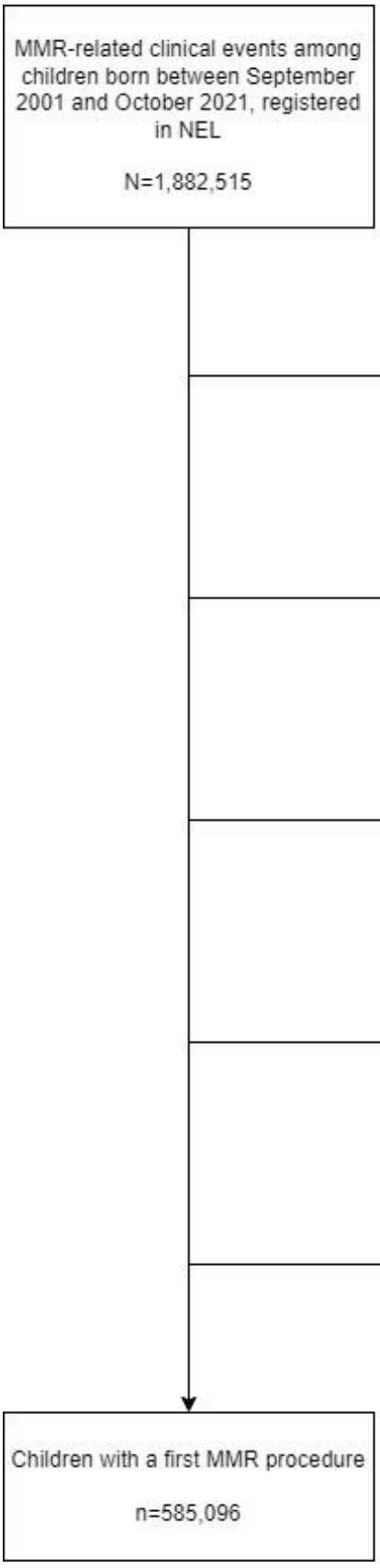


We excluded 656,043 (55.0% of 1,192,630) registrations, which were not current at 12 months of age. For children with multiple concurrent registrations at the time of their first birthday, we applied the following sequence of hierarchical rules to determine which registration should be retained:

Retain

1. *registration with the most recent start date*
2. *registration with a NULL end date (considered more recent/ongoing)*
3. *registration with the most recent end date*
4. *registration with the lowest address identification number (children may have multiple registrations starting and ending on the same date as a result of practice mergers and closures. The lower address identifier is assumed to relate to the original registration)*

Figure S2 – Processing the MMR data file



Data relating to MMR vaccinations were extracted separately. The data file was in long format where each row was a unique clinical code, therefore children often have multiple rows indicating various MMR administrative processes and procedures throughout their life, including vaccination invitations, declines, procedures, contraindications, appointment non-attendance, as well as clinical codes relating to the second MMR vaccination. For the purposes of this study, it was necessary to identify the ***first MMR procedure*** *for each child. Of 1,882,515 events, 516,358 recorded events were removed as they were not considered to be a first MMR procedure (see table S1). Records without a date (n=3), as well as duplicate records were removed (n=664,538). Finally, all but the earliest event if a child had more than one MMR vaccination recorded were removed (n=116,520). MMR vaccinations given before the child's first birthday were excluded if the child received another dose after turning 12 months of age, as per guidance from The Green Book.*[1] *Where available, subsequent MMR records were treated as the child's first vaccination, otherwise early MMR vaccinations were retained in the dataset and later considered as "not timely".*

[1] Public Health England. Measles: the green book, chapter 21. In: Public Health England, ed. The Green Book; 2019.

Table S1 - SNOMED clinical codes for first MMR procedures

Events recorded in the primary care electronic heath record using another clinical coding system (e.g. Read v2 or EMIS local codes) have been mapped to relevant SNOMED codes within the Discovery Data Service. This ensures that searching the database using SNOMED codes captured all events regardless of the clinical coding system used.

SNOMED concept ID	Other code	Clinical coding scheme	Code description
38598009	38598009	SNOMED	Measles-mumps-rubella vaccination (procedure)
	65M1.	Read v2	Measles/mumps/rubella vaccn.
	^ESCT1405772	EMIS local	Administration of measles and mumps and rubella vaccine
47435007	47435007	SNOMED	Measles vaccination (procedure)
	65A..	Read v2	Measles vaccination
	65A1.	Read v2	Measles vaccination
	ZV042	Read v2	[V]Measles vaccination
	^ESCT1405845	EMIS local	Administration of measles vaccine
50583002	50583002	SNOMED	Mumps vaccination (procedure)
	65F5.	Read v2	Mumps vaccination
	ZV046	Read v2	[V]Mumps vaccination
	^ESCT1405876	EMIS local	Administration of mumps vaccine
82314000	65B..	Read v2	Rubella vaccination
	ZV043	Read v2	[V]Rubella vaccination
	^ESCT1406118	EMIS local	Administration of rubella vaccine
170364006	65A2.	Read v2	Measles vaccin.+immunoglobulin
432636005	^ESCT1408534	EMIS local	Administration of measles and mumps and rubella and varicella virus vaccine
871909005	^ESCT1397548	EMIS local	Administration of first dose of measles and mumps and rubella and varicella virus vaccine
150971000119104	ZV064	Read v2	[V]Measles-mumps-rubella (MMR) vaccination
308081000000105	65M10	Read v2	First MMR (measles mumps and rubella) vaccination
	Xaeec	Read v3	First MMR (measles mumps and rubella) vaccination
	^ESCTME809974	EMIS local	Measles mumps and rubella vaccination - first dose
505001000000109	9ki1.	Read v2	MMR catch-up vaccination - enhanced services administration
	XaQPr	Read v3	Measles mumps rubella catch-up vaccination
571591000119106	^ESCT1409651	EMIS local	Administration of live attenuated measles mumps and rubella vaccine
1037251000000100	65M11	Read v2	First MMR vaccination given by other healthcare provider
	Xaeeq	Read v3	First MMR vaccination given by other healthcare provider

We included clinical codes relating to administration of mono-components of the first MMR vaccination. After removal of duplicate data entries and merging to the study cohort, 533 children had a clinical code for measles vaccination, and two for mumps vaccination, as opposed to a combined MMR vaccination.

Table S2 – Proportion of children within each cohort who had a MMR procedure recorded in their electronic primary care record

The two datafiles (registrations and MMR procedures) were merged. 531,469 children with an MMR procedure were not matched to the study denominator because they were not eligible for a timely MMR vaccination in the 19 months before or after 23rd March 2020.

	MMR procedure	No MMR procedure	Total
Pre-pandemic (%)	28,173 (84.8)	5,053 (15.2)	33,226 (100)
Pandemic (%)	25,454 (78.5)	6,992 (21.5)	32,446 (100)

Table S3 – SNOMED clinical codes for measles and mumps diagnoses

Code term	SNOMED Concept ID
Measles (disorder)	14189004
Mumps (disorder)	36989005

Table S4 – Ethnic background distribution by Clinical Commissioning Group

	White (%)	Mixed and Other (%)	South Asian (%)	Black (%)	Missing (%)	Total (%)
Barking & Dagenham	2,136 (27.6)	567 (7.3)	1,164 (15.1)	772 (10.0)	3,096 (40.0)	7,735 (100)
City & Hackney	2,713 (28.9)	1,942 (20.7)	162 (1.7)	576 (6.1)	4,009 (42.6)	9,402 (100)
Havering	3,171 (43.2)	500 (6.8)	484 (6.6)	353 (4.8)	2,833 (38.6)	7,341 (100)
Newham	2,698 (21.3)	1,656 (13.1)	3,572 (28.2)	1,083 (8.6)	3,659 (28.9)	12,668 (100)
Redbridge	2,595 (26.6)	1,032 (10.6)	2,821 (28.9)	404 (4.1)	2,912 (29.8)	9,764 (100)
Tower Hamlets	1,223 (13.3)	585 (6.4)	2,419 (26.3)	261 (2.8)	4,715 (51.2)	9,203 (100)
Waltham Forest	3,981 (41.7)	1,297 (13.6)	1,061 (11.1)	597 (6.3)	2,623 (27.4)	9,559 (100)
Total	18,517 (28.2)	7,579 (11.5)	11,683 (17.8)	4,046 (6.2)	23,847 (36.3)	65,672 (100)

Table S5 – Index of Multiple Deprivation quintile associated with LSOAs with less than 60% of children receiving timely MMR vaccination in the pre-pandemic and pandemic cohorts

	LSOAs with <60% timely vaccination in pre-pandemic cohort (*n*=90)		**LSOAs with <60% timely vaccination in pandemic cohort (*n*=153)**		**All LSOAs (*n*=1,203)**	
	n	**%**	**n**	**%**	**n**	**%**
Most deprived	30	33.3	63	41.2	401	33.3
2	45	50.0	61	39.9	445	37.0
3	9	10.0	19	12.4	187	15.5
4	2	2.2	6	3.9	107	8.9
Least deprived	2	2.2	4	2.6	58	4.8
Missing	2	2.2	0	0.0	5	0.4
Total	90	100	153	100	1203	100

Table S6 – Unadjusted and adjusted odds of timely MMR vaccination

	Unadjusted		**Adjusted[1] (*n*=65572[2])**	
	OR[3]	**95% CI[4]**	**OR[3]**	**95% CI[4]**
Cohort				
Control (ref.)	1		1	
COVID-19	0.80	0.77,0.83	0.79	0.76,0.82
Sex				
Male (ref.)	1		1	
Female	1.07	1.03,1.11	1.07	1.03,1.11
CCG[5]				
Barking & Dagenham	0.84	0.78,0.89	0.88	0.82,0.94
City & Hackney	0.60	0.56,0.63	0.67	0.63,0.71
Havering	1.78	1.64,1.92	1.53	1.40,1.66
Newham (ref.)	1		1	
Redbridge	0.82	0.77,0.87	0.69	0.64,0.73
Tower Hamlets	1.52	1.42,1.63	1.52	1.42,1.64
Waltham Forest	1.21	1.13,1.29	1.21	1.14,1.30
Ethnic background				
White (ref.)	1		1	
Mixed and Other	0.68	0.64,0.73	0.77	0.72,0.82
South Asian	1.33	1.25,1.41	1.39	1.30,1.48
Black	0.64	0.59,0.69	0.70	0.65,0.76
Missing	0.75	0.72,0.79	0.77	0.74,0.81
IMD[6] quintile				
Most deprived (ref.)	1		1	
2	1.03	0.99,1.07	1.03	0.99,1.08
3	1.26	1.18,1.33	1.24	1.16,1.32
4	1.87	1.71,2.06	1.78	1.61,1.98
Least deprived	2.42	2.07,2.82	2.09	1.78,2.46

[1] Model mutual adjusting for cohort, sex, clinical commissioning group, ethnic background and Index of Multiple Deprivation quintile. [2] 98 children with missing Index of Multiple Deprivation quintile and two children with "Other" sex were excluded from the adjusted model. [3] Odds ratio. [4] 95% confidence interval. [5] Clinical Commissioning Group. [6] Index of Multiple Deprivation.

Table S7 – Measles and mumps cases recorded in primary care in the pre-pandemic and pandemic periods by Clinical Commissioning Group

	Pre-pandemic	Pandemic
Measles	325	20
Mumps	140	34